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ALLIS-CHALMERS Electrical REVIEW

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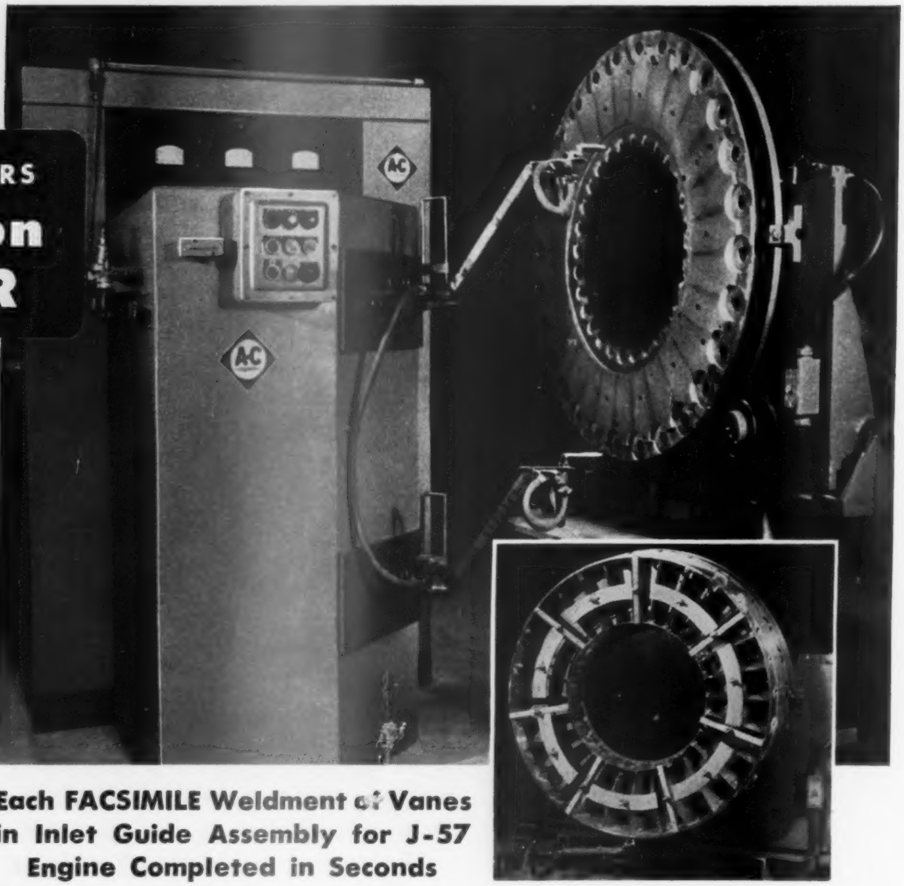
Precision Brazes at Jet Speeds

ALLIS-CHALMERS **Induction HEATER**



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Electrical REVIEW

THE COVER

ELEMENTAL PHOSPHORUS is the product made in the giant arc furnace powered by this core and coil assembly. The tremendous currents carried by the circular secondary coils and heavy buswork made an interesting design problem. The article "Powering a Giant Arc Furnace," on page 10, tells of the transformer's design and applications.

Allis-Chalmers Staff Photo by Harold Shrode

Allis-Chalmers

ELECTRICAL REVIEW

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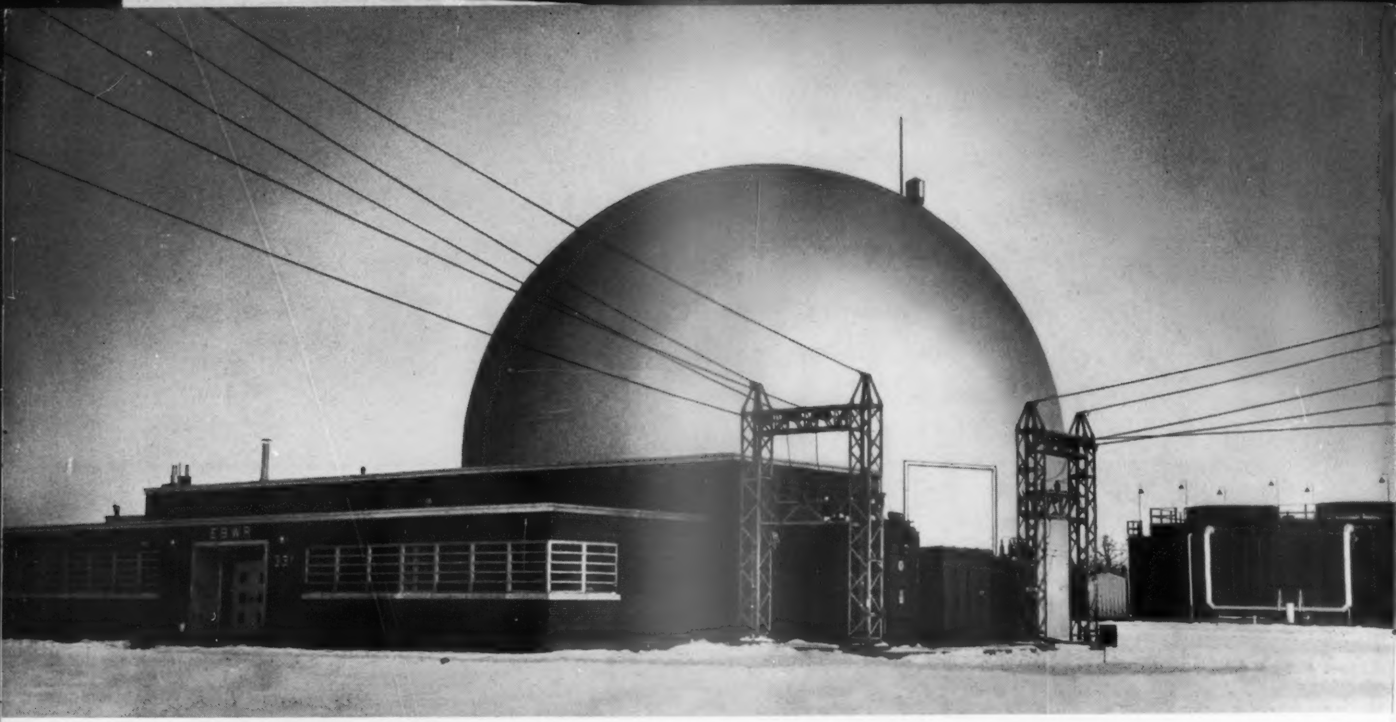


ARGONNE LABORATORY'S EBWR plant is located at Lemont, twenty-five miles southwest of Chicago, Ill.

ARGONNE AND THE ATOM

by C. R. BRAUN
and
K. H. GRUENWALD
Nuclear Power Division
Allis-Chalmers Mfg. Co.

On December 1, 1956, ahead of schedule, Argonne National Laboratory's EBWR went "critical." Continuous operation began February 9, 1957.

THE FIRST CIVILIAN NUCLEAR POWER SYSTEM in the United States to be designed and built solely for experimentation in electric power generation was formally dedicated February 9, 1957. On that date, Admiral L. L. Strauss, Chairman of the Atomic Energy Commission, threw the switch that placed the Experimental Boiling Water Reactor power plant of the Argonne National Laboratory at Lemont, Illinois, in continuous full power operation.

Now supplying a major portion of the electrical requirements for the laboratory, this Boiling Water Reactor is one of the original five reactor projects in the AEC civilian power development program which was launched in 1954. The other four are: Fast Breeder Reactor, Sodium Graphite Reactor, Homogeneous Reactor, and Pressurized Water Reactor.

First to be completed and to generate electricity, the Experimental Boiling Water Reactor was developed in conceptual design by the Argonne National Laboratory. This laboratory also supervised the entire project. Formal dedication was preceded by full power operation on December 29, 1956. The reactor went "critical" for the first time on December 1, ahead of schedule. The term "critical" means that point at which the chain reaction becomes self-sustaining. Rated at 20,000 kw of heat and 5000 kw of electricity, this plant is the culmination of one and a half years of construction work. Prior to the EBWR project, Argonne National Laboratory conducted a series of boiling water reactor experiments beginning with "Borax I."

Their first boiling water reactor experiment was conducted at the National Reactor Testing Station, Arco, Idaho, in 1953. A second experimental boiling water reactor was constructed in the summer of 1954 and went critical later in that year. In 1955, Borax III was operated successfully at power loads up to that necessary to produce about 2000 kw of electricity. This was the first reactor in the United States to supply experimentally the power and light for an entire city (Arco, Idaho, July 17, 1955). The research and development information gained from these smaller reactors served as a basis for the EBWR development.

Steam from reactor drives turbine

The principal advantage of the EBWR flow cycle is its basic simplicity, as shown in Figure 1. It is the only reactor design conceived to date which delivers the steam, generated in the reactor pressure vessel, directly to the

turbine, shown in Figure 2. Eliminating heat exchangers is a very distinct advantage, since they are an expensive and complicated part of other reactor cycles.

Heat from the fission of uranium atoms in the slightly enriched fuel elements, 1.4 percent U-235, of the reactor core causes water to boil, producing steam at 600 psig and 488 F. The rate of heat generation is varied by moving the neutron-absorbing control rods in the core. These rods, fabricated from hafnium or boron alloys, are actuated by mechanical drive mechanisms located in a room beneath the reactor.

Steam generated in the reactor core rises into the steam dome of a 7-foot diameter, 25-foot high pressure vessel where most of the water droplets separate from the steam. This feature of the reactor is important, since very little radioactivity is carried from the reactor in dry steam. The steam then passes through the steam dryer where any remaining moisture is removed. The steam dryer also serves as an emergency shutdown cooler to dissipate the approximate 6 percent reactor decay heat.

Beyond the steam dryer, the main steam line divides, as indicated in Figure 1, with one branch going to the turbine and the other to the bypass control system. The primary function of this bypass system is to maintain pressure in the main steam line at any selected value between 100 and 650 psig. Essentially a dumping device, this system compensates for changes in steam flow to the turbine resulting from generator load fluctuations. When a load change occurs, excess steam from the reactor flows into this system while the power level of the reactor is being adjusted to a value corresponding to the new load. Excess steam passes through a bypass valve and desuperheater line to the main condenser. Steam is also discharged into the desuperheater line by the overpressure relief system, which is comprised of two conventional pop safety valves and a special relief and regulating valve.

Special sealing keeps steam in — air out

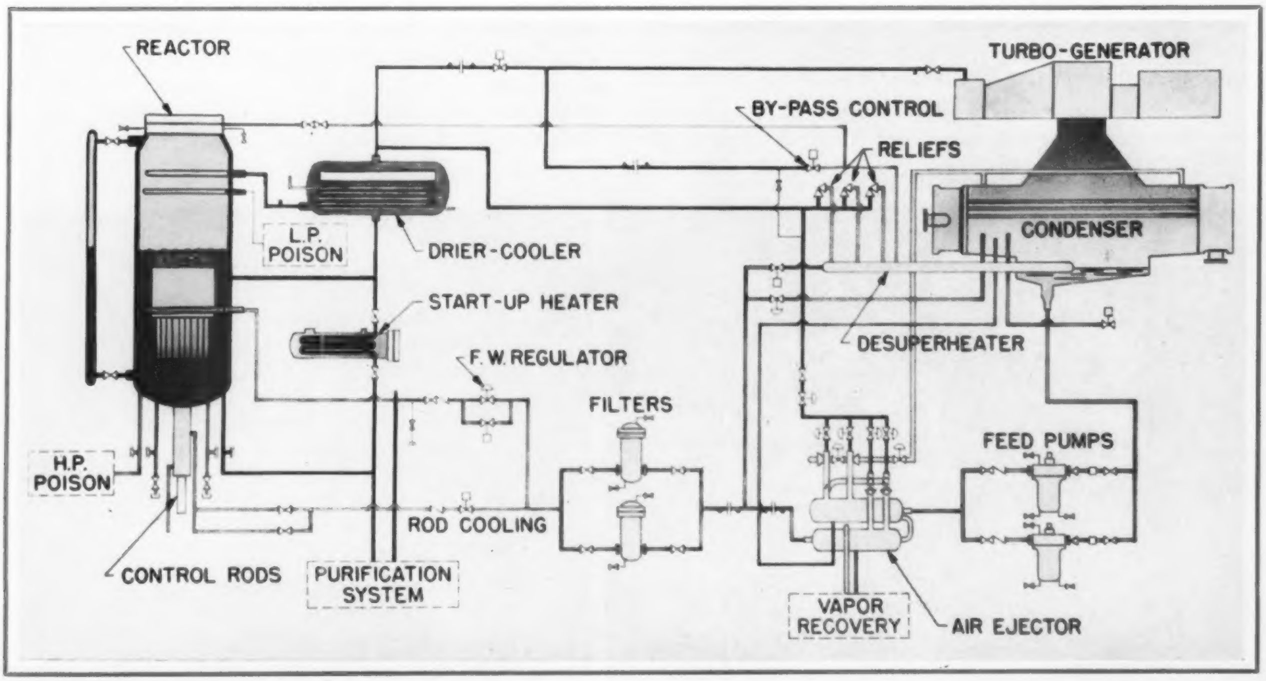
The turbine, while conventional in most respects, incorporates several unique design features developed to prevent outleakage of radioactive steam and inleakage of ambient air. In addition to the conventional complement of seals, a special sealing arrangement, indicated in Figure 3, is used. Effective sealing is accomplished by means of a dry air barrier, a vacuum leakoff and a steam seal. Steam seal regulators, manifolds and interconnecting piping, together with connections to the reactor water recovery and air-drying system, assure that any seepage is returned to the system.

To reduce erosion in the exhaust rows of the turbine, moisture-deflecting lips are used on the diaphragm faces of the last two rows and interstage drains are incorporated. In addition, the leading edge of each bucket in the last row is protected with a layer of stellite.

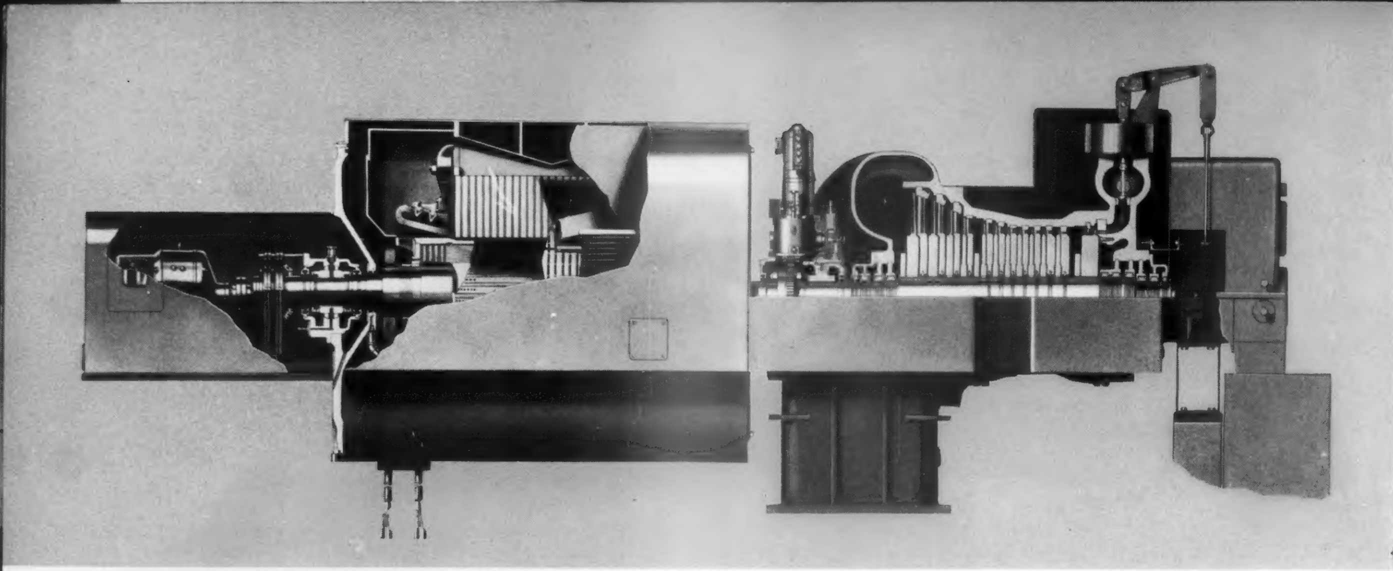
After the steam has released its energy to the turbine, it is exhausted to a 5300-square-foot surface condenser, shown in Figures 4 and 5.

The condenser, located in a horizontal position directly below and parallel to the turbine, has a divided water box and provides a single-pass cooling water circuit. It incorporates an air-cooling section at each end and a deaerating hotwell of 250 gallons capacity.

To assure complete isolation between the circulating cooling water and the steam cycle, double tube sheets are used at each end of the condenser tubes, as illustrated in Figure 6. The space between the tube sheets is evacuated



SIMPLIFIED FLOW DIAGRAM of the EBWR reactor and power cycle shows components involved in the steam and condensate cycle. Bypass control system, not required on conventional steam boiler-turbine cycles, shunts excess steam through the desuperheater to the condenser so that minor changes in turbine steam demand have no immediate effect on reactor operation. Future experimental operation planned for EBWR called for maximum of both flexibility and safety in components. **(FIGURE 1)**



5000-KW TURBINE-GENERATOR built for EBWR plant embodies several departures from conventional turbine design. Among those shown in this drawing, the gland sealing system at both ends of the turbine is new, a turning gear is included and the flanges for both the valve chest cover and main turbine horizontal joint are sealed with welded-on enclosures. **(FIGURE 2)**

to a 6-inch pipe within a 1200-gallon drain tank to trap and bypass circulating water if a leak develops. A sight glass mounted on drain tank is used to indicate leakage.

Metallurgically clad aluminum is used for the condenser tubes in place of conventional copper bearing alloys. Since the radioactivation absorption cross section of aluminum is less than copper, the radioactivity level in the reactor circuits is substantially reduced. In this way, a potential maintenance hazard is markedly reduced.

Condenser tubes directly exposed to water particles from the turbine exhaust steam are protected by stainless steel shields. Water boxes and the hotwell are longitudinally divided to permit plant operation to continue even if a tube should rupture. Conductivity cells in the condensate lines assure that any tube rupture will be detected promptly, thereby indicating which half of the condenser must be shut down to prevent contamination of reactor water by the circulating water.

Condensate from the hotwell is pumped by a combination condensate and reactor feed pump, shown in Figure 7, through the high pressure intercoolers and aftercoolers of the twin two-stage steam jet air ejectors.

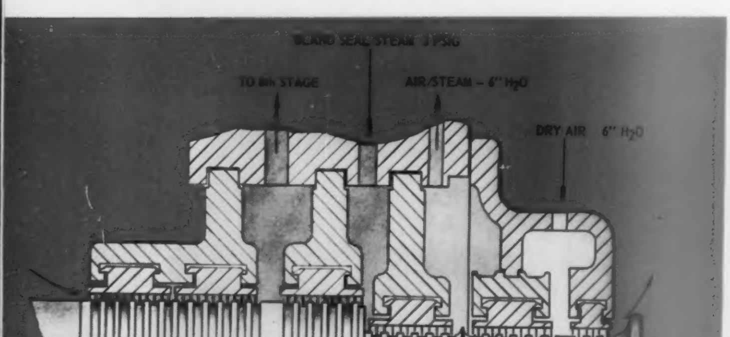
To reduce possible leakage, pump shaft seals were eliminated wherever practical. For example, instead of separate condensate and feed-water pumps, a single eight-stage unit combines these two functions. Further reduction in the number of shaft seals was realized by the use of a fluid piston type water-lubricated bearing at the lower end of the pump shaft. The upper end of the pump shaft is rigidly coupled to the motor shaft.

The remaining upper pump shaft seal consists of three separate sections: a labyrinth-type seal, a rotary mechanical seal and a serrated bushing as shown.

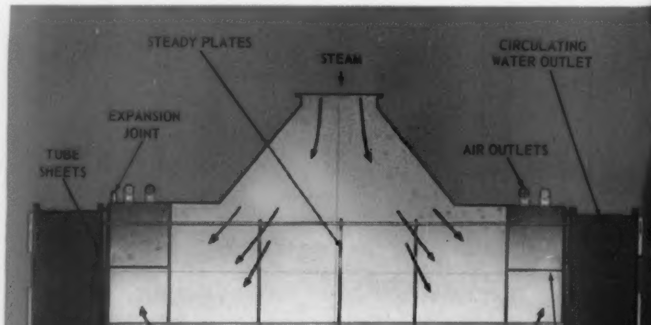
After flowing through the air ejector coolers, the reactor feed water passes through full flow filters and back to the reactor, the point of origin for the steam cycle.

Auxiliary systems vital to satisfactory operation

In addition to the basic flow cycle, several auxiliary flow systems are employed to assure proper operation and control of this reactor power plant. A high pressure boric



FOUR-COMPARTMENT turbine gland seals for turbine minimize outleakage of steam or inleakage of air-borne moisture, reducing radioactivity problems or dilution of valuable heavy-water vapor. **(FIG. 3)**



SURFACE CONDENSER, 5300 sq ft, included several departures from conventional design. Water box is divided so that unit can operate temporarily if water to steam leak should develop. **(FIG. 4)**

acid system, indicated in Figure 1 as H.P. Poison, is used for rapid emergency shutdown of the reactor. Boric acid, which is a strong neutron absorber, is held in a tank at 1600 psig with sufficient air above it so that 160 gallons of solution can be injected into the reactor vessel within a matter of seconds to reduce the reactivity.

Another auxiliary system vital to satisfactory operation is the reactor water purification cycle. In this system, reactor water is continuously purified by a side stream system which takes water from the reactor at a rate of 10 gpm, cools it to 110 F, sends it through a prefilter, then through a mixed-bed ion exchanger which removes essentially all ionic and most colloidal impurities. A 2-micron after-filter prevents carryover of resin into the reactor. The demineralized water from the resin bed is pumped by hermetically sealed pumps back into the reactor feed-water line through regenerative heat exchangers where its temperature is raised to 400 F.

Heavy water may lower future power costs

Future use of heavy water as moderator and coolant may result in lower overall power costs because its superior moderating quality results in greater neutron economy. However, heavy water, D_2O, is high in initial cost and will make even minute losses significant. Consequently, an extensive reactor water recovery and air-drying system has been incorporated to assure virtually no loss of this $233-per-gallon liquid. Leak tightness guarantees in the power cycle are stringent. Leakage specifications for EBWR require that not more than one pound of water outleakage and one-half pound inleakage be permitted per day. In conventional plants leakage of approximately 1000 pounds per day is considered acceptable practice.

Functionally, this recovery system, sketched in Figure 8, is divided into two parts: a water recovery section and a dry air make-up section. The water recovery section consists of three major units: First, a water-cooled primary vent condenser cools air and water vapor from the seals down to a temperature of approximately 120 F. Second, a refrigerated cooler which lowers the air vapor mixture temperature still further. Third, a chemical dryer which removes the remaining moisture from the air by solid adsorption.

The second section serves to replace dry air lost through seals in the system. It consists of a refrigerated cooler and a chemical dryer that removes moisture from the room air.

Dry air produced by this equipment is returned to the various shaft seals at a –40 F dewpoint. This is equivalent to a moisture content of 0.5 grain per pound of air produced.

Proven safety features are incorporated

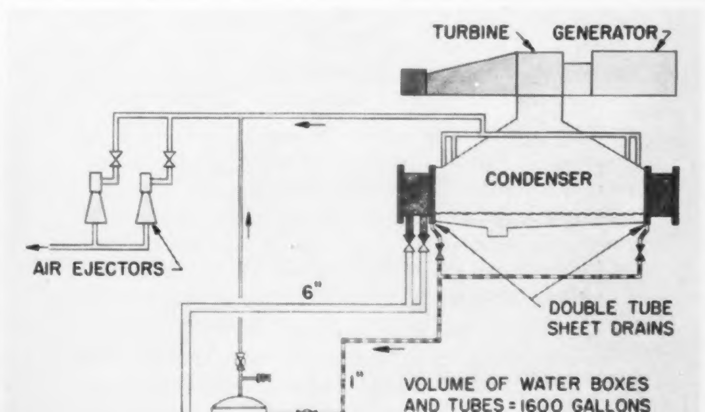
Operating experience gained from this plant and the Borax units has clearly demonstrated the safety of boiling water reactors. Safety was high on the list of design requirements for every item built into this Experimental Boiling Water Reactor plant.

Power reactor safety depends largely on a strong negative temperature coefficient of reactivity, a condition inherent in boiling water reactors. This coefficient determines whether a reactor will become more or less critical with an increase of temperature. In a reactor having a negative temperature coefficient reactivity is reduced as the reactor heats up.

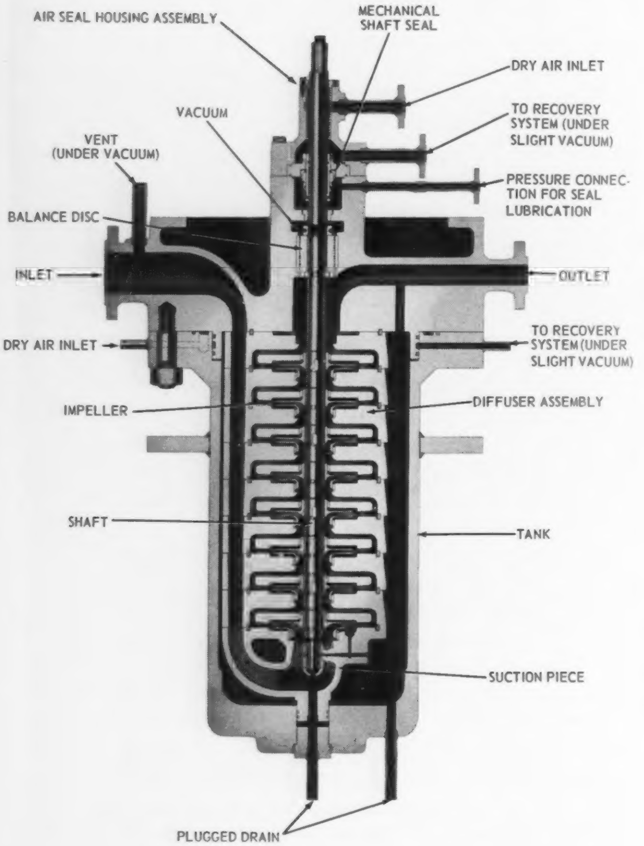
All equipment associated with the power-generating cycle is housed in an 80-foot diameter gastight steel shell designed for an internal pressure of 15 psig. To enter this shell, shown on page 12, one must pass through the service building which is connected to the power plant by a gastight air lock. Doors of the air lock are mechanically linked to prevent opening one door unless the other is closed and sealed.

To provide emergency cooling, a 15,000-gallon reservoir of water is suspended from the dome of the building.

CONDENSER LEAKAGE at tube sheet joints can be detected immediately. Drain lines connect the space between the double tube sheets to a tank evacuated by the plant's air ejector system. **(FIG. 6)**



LEAK TIGHTNESS OF CONDENSER tubes was assured by careful checking against leakage at joint between tubes and tube sheets. Note double tube sheet construction. **(FIG. 5)**



REACTOR FEED-WATER PUMPS combine function of both condensate and boiler feed pumps in conventional plant. This construction reduces leakage by limiting shaft seals to one. Motor thrust bearing carried total vertical thrust. Radial thrust at lower end of shaft is handled by fluid piston type water-lubricated bearing. (FIG. 7)

When discharged through the building spray system, this water can quickly reduce the steam pressure resulting from even a major rupture of the pressure vessel or piping. Simultaneously, suspended radioactivity would be washed from the building atmosphere.

Even the heating system is modified to retain the gastight feature. The power plant building is heated and cooled by conventional air-conditioning units, which discharge exhaust air through duct work near the top of the steel shell. Quick-closing valves in the inlet and outlet air ducts close upon detection of radioactivity in the plant air, thereby protecting the gastight feature of the building.

Operation of the entire power plant, from start-up to shutdown, is centralized in a control room located outside the power plant building. Industrial television is used to bring a direct view reading of the reactor pressure gage and water level into the control room. Location of the control room was also dictated by safety considerations. Operators will be able to inspect the plant during each eight-hour shift.

Results confirm confidence in design

Tests so far conducted have shown that the reactor will function satisfactorily at full operation. Its performance is welcomed justification of the steadfast beliefs and pioneering efforts by the scientific and technical staff of the Argonne National Laboratory and the companies who assisted in the project. The next step is to gain experience in continuous operation and assurance that stable conditions can be maintained over long periods of time.

One of the major problems in developing the boiling water reactor was that of achieving stability. Each steam bubble creates a void in the reactor core. These voids cause the nuclear reactor to slow down. Should the steam bubbles collapse, the nuclear reactivity increases. While this effect is good in that it makes the reactor self-regulating to a large extent, it can cause oscillations within the reactor. The designers of the EBWR have endeavored to minimize the oscillation effects without reducing the self-regulating characteristics.

In addition to continuous operation tests, a series of experimental operations will be conducted with various core arrangements within the present reactor. Critical experiments, control rod calibrations and measurement of various coefficients are among the items.

The effects of a number of variables on the power and stability will be tested. These variables will include water level, steam demand, and core diameter. Also, the response of the reactor to planned power variations may be tested.

Designed initially to handle either light-water or heavy-water systems, the reactor will be modified to permit experiments with forced circulation in the core. Some equipment for these experiments is already installed. The components that cannot be altered are designed to meet future requirements. A 40-megawatt, heavy-water core of a size similar to the present light-water core can be handled in the system.

The reactor vessel is extremely flexible in design. Every component influencing core structure, core position and fuel assembly is replaceable. Only the locations of control rod penetrations through the lower head of the reactor vessel are unchangeable. This is not a serious limitation, since there are a number of lattice arrangements that can be made using the present control rod pattern.

Forced recirculation ups reactor output

Boiling reactor studies indicate that large gains in specific power can be achieved by forced recirculation within the core. A circulation system has been designed which, with the present core, may deliver approximately 50% more power at the same steam void fraction present in 20-megawatt natural circulation operation. Further, since improved reactor stability should result from forced circulation, it may be feasible to increase the steam void fraction and thus obtain a total reactor power rating much larger than the present 20-megawatt rating.

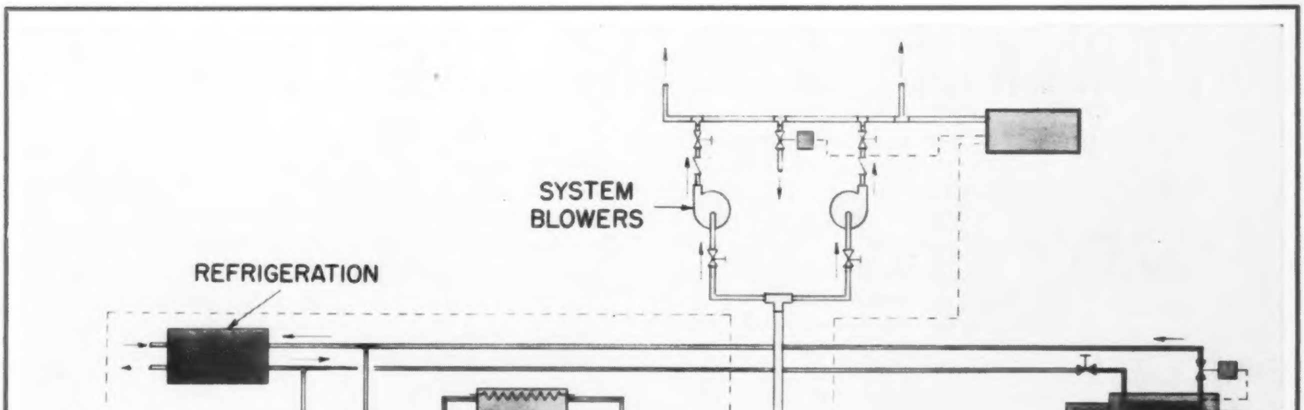
The more significant aspects of recirculation will be realized in operation with a smaller core diameter. By increasing the coolant (water) velocity by a factor of at least 4, and with an average steam void fraction

in excess of 20 percent, the reactor power density could be increased possibly fivefold over the present value. At these high power densities, the limitation on reactor power would no longer be the boiling stability. Instead, the limitation becomes the established heat flux limitations on the fuel elements. A small core may be installed in the EBWR some time in the future to investigate such effects. Definite plans have been established to test a heavy-water core in the EBWR early in 1958. This core will be designed to operate primarily with recirculation.

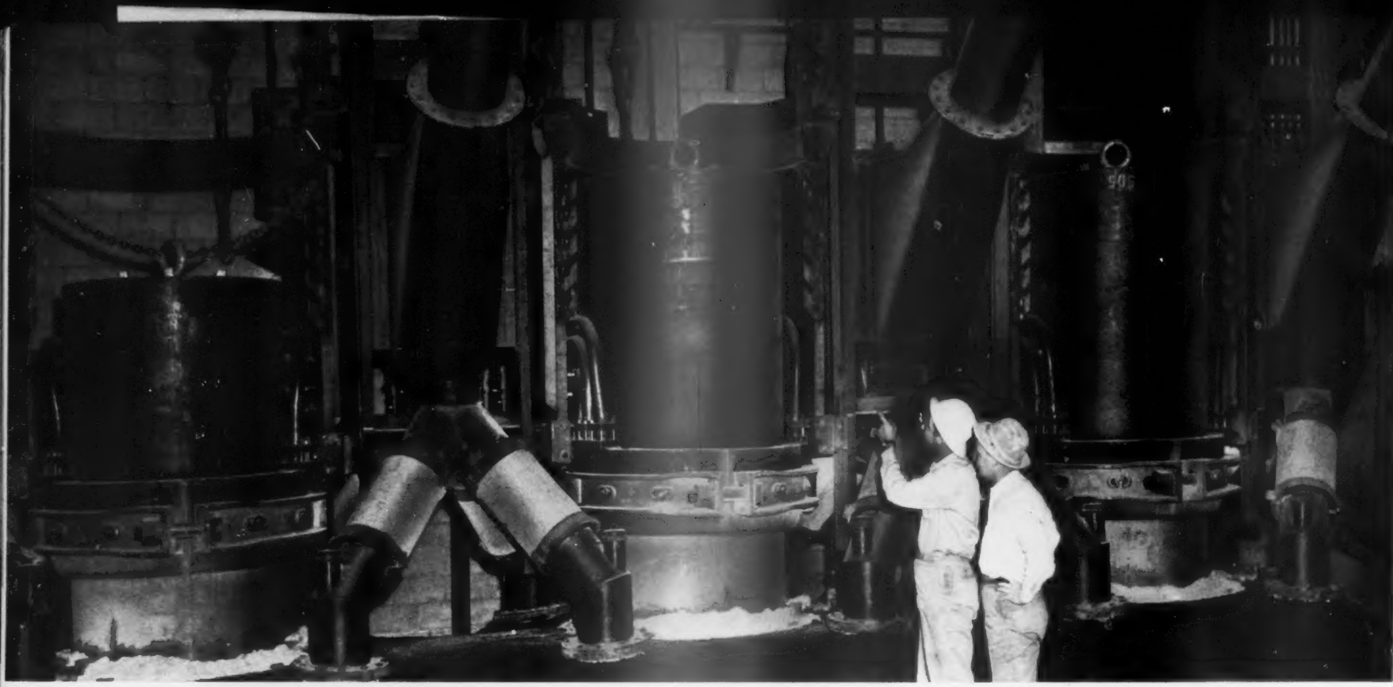
Experiments conducted by the Argonne National Laboratory with this EBWR, together with developments presently under investigation by reactor designers, will lead to further improvements in nuclear power generation. These programs will speed the day when the generation of electric power from atomic energy will be competitive with conventional power plants. When this happens, the same phenomenal growth experienced by conventional steam turbine generator units — from 25,000 kw to 500,000 kw in a relatively few years — is anticipated for nuclear power plants.

EBWR DATA

Capacity	5000 kw
Steam pressure, turbine inlet	560 psig
Steam temperature, turbine inlet	482 F
Feed-water temperature	109 F
Steam flow	62,700 lb/hr
Reactor	
Power (heat)	20,000 kw
Core diameter	4 ft
Core length	4 ft
Reactor vessel height	25 ft
Reactor vessel diameter	7 ft
Steam pressure	600 psig
Steam temperature	488 F
Other Data:	
Reactor building diameter	80 ft
Reactor building height	119 ft



REACTOR WATER RECOVERY-AIR DRYING SYSTEM is entirely automatic in operation. Section at left recovers steam vapor leakage from, and maintains negative pressure on, the seals in turbine, valves, and pumps. Dry air make-up section at right removes moisture from plant air before supplying it at slight pressure to dry air chambers of the various seals. **(FIGURE 8)**



HUGE ELECTRODES, spaced on 9½-foot centers, bring power to the furnace's submerged arcs. **(FIGURE 1)**

POWERING A GIANT ARC FURNACE

by **G. H. GILBERTSON**
Vice-President
Shea Chemical Corp.
Jeffersonville, Ind.
and
JOHN A. EBERT
Transformer Dept.
Allis-Chalmers Mfg. Co.

Giant furnace takes giant transformer to power enormous electrodes.

THE INCREASE in ratings of the electric reduction furnaces for the production of elemental phosphorus has been matched only by the spectacular growth in the demand for phosphorus products. Today, a single phosphorus furnace the size of Shea Chemical Corporation's No. 2 can produce in one year nearly a third of the quantity made by the entire industry in the same period a decade ago.

Although phosphorus, the "light-bearer," was isolated from organic matter in 1669, until 1897 the phosphorus of commerce was made by reacting phosphate rock with sulphuric acid. In that year, the first electric furnace for the production of elemental phosphorus was constructed at Niagara Falls, N. Y. But another half century was to intervene before elemental phosphorus production was to hit the strides which have characterized the last decade.

In 1939, the phosphorus production of the country was about 43,000 tons per year. By 1947, it had doubled. It was then that the spectacular demands for phosphorus salts for synthetic detergent production really began. By 1950 synthetic detergent production tripled, and elemental phosphorus production — to meet this growth — doubled to about 153,000 tons per year. Since then, each has about doubled again and today phosphorus production approaches 300,000 tons per year.

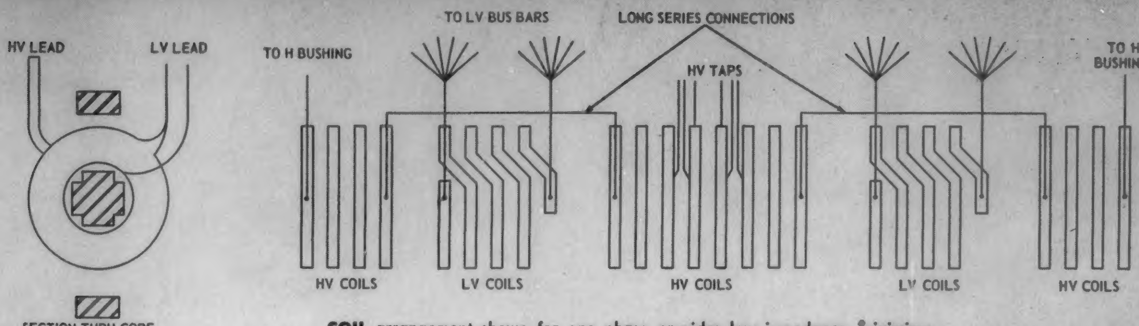
Expanding to fill these market needs, Shea Chemical, organized less than 5 years ago, now expects about six times the sales it had in its first full year of operation, 1953. To do so, a second phosphorus furnace and two new sodium phosphate-phosphoric acid plants were constructed.

While a power load of about 8000 kva characterized the phosphorus furnaces of the 1930's, 12,000 kva was typical of those of the 1940 vintage. Then came the period of rapid growth and almost each succeeding furnace was of greater capacity than its predecessor. When Shea's initial furnace was constructed in 1953, the 34,000-kva unit was a giant of its day.

Making the latest big increase in output possible is Shea's new No. 2 furnace and its 42,000-kva water-cooled transformer. An idea of the furnace's size can be gained from the 45-inch diameter electrodes shown in Figure 1. Each electrode is made up of three 108-inch long sections of graphite screwed together with graphite pins.

A different type of bus-bar arrangement between the transformer and the furnace requires less copper than in Shea's No. 1 unit and gives greater power efficiency. This efficiency is gained by forming the transformer secondary delta connections on the furnace electrodes rather than in a bundle at the rear of the furnace.

There are three general types of arc furnaces in use today: indirect arc, exposed arc, and submerged arc. The first type is used in small single-phase installations for melting or refining small quantities of metal. The larger three-phase furnaces are usually the exposed-arc type and



COIL arrangement shown for one phase provides low impedance, minimizes short-circuit stress and simplifies secondary internal connections. **(FIGURE 2)**

are used for melting and refining steel. The submerged-arc type is used for melting nonmetallic materials and for oxide reduction in the production of phosphorus, iron, cobalt, nickel, and other elements. The furnace in Figure 1 is of the latter type. The secondary voltages required for furnaces of this type may vary from 150 volts to over 500 volts, with secondary line currents in the large units as high as 50,000 amperes.

Special requirements mean special design

Designing and building a large furnace transformer involves solving problems different than those found in making even the highest kva power transformers. These problems are imposed by the large conductor and few turns of the secondary winding. In addition, normal design requirements common to all transformers must be met.

To make this a well-designed furnace transformer, embodying all the necessary electrical, mechanical, and economic features, the following are needed:

1. Low impedance — approximately 6 percent.
2. Secondary windings carrying up to 50,000 amperes.
3. Forced oil-to-water cooling.
4. Temperature guarantee of 55 C rise over ambient.
5. No-load tap changes with the necessary steps required for good furnace performance.
6. High voltage windings quickly and easily connected for either wye or delta operation.
7. Efficiency at full load over 99 percent.

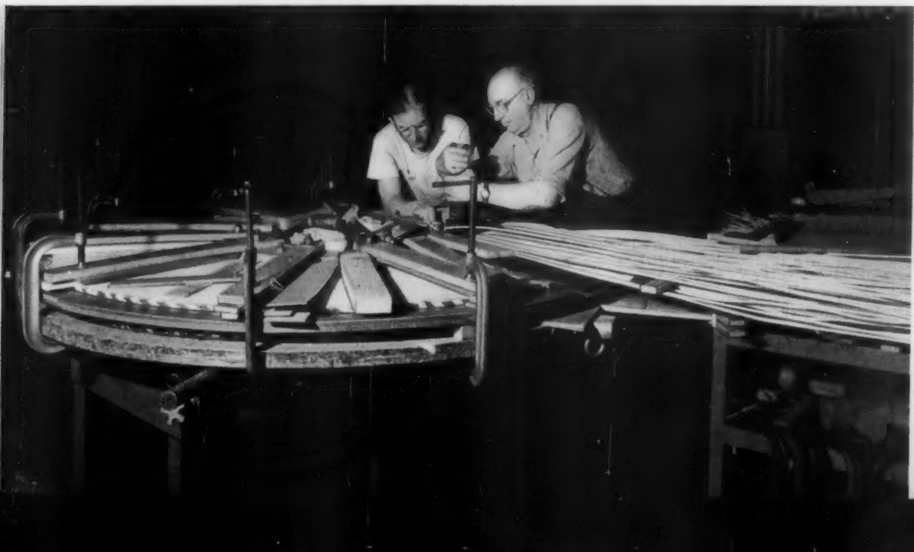
Each of these seven design requirements influences the physical arrangement, the materials required, and the construction methods. The designers' job is to make an optimum design combining all these features.

To obtain low impedance, a shell-form unit with a two-group coil arrangement having four impedance groups was chosen. The coil arrangement shown in Figure 2 is typical for a shell-form furnace transformer. The low voltage copper was so large that making a long series connection was impractical. The high voltage coils, therefore, were placed in the center and at the ends of the stack, and the two long series connections were made using the high voltage conductor. The two low voltage groups were connected to bus bars and were paralleled. This coil arrangement is a natural outgrowth of the impedance requirement, coupled with the limitations imposed by the physical size of the low voltage conductor.

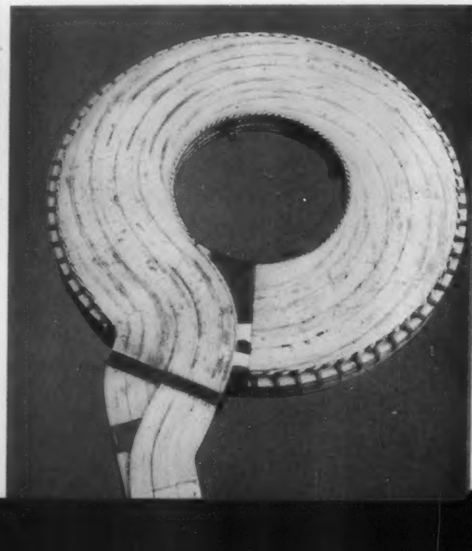
Associated with low impedance is a high short-circuit stress. In this case a thrust of several hundred thousand pounds is exerted upon the end frames under short-circuit conditions. This short-circuit force is predominantly axial; that is, in a plane perpendicular to the face of the coils and tending to force the high and low voltage coil groups apart. To withstand this force it is necessary to clamp the coils together in the axial direction. Clamping is accomplished by means of structural end frames and bolts of sufficient cross section.

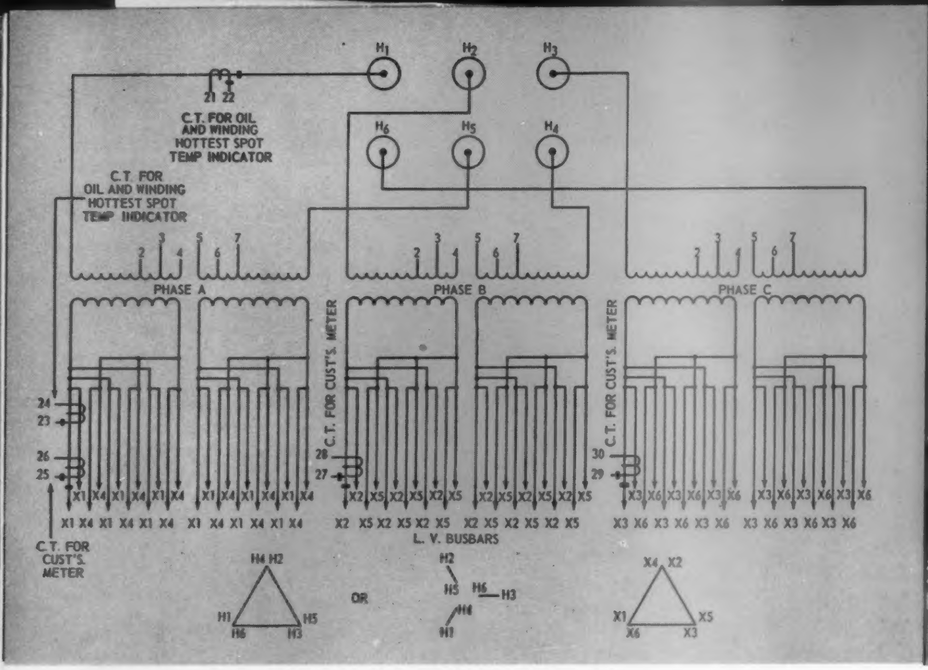
A forced-cooled transformer carrying these large secondary currents may require a low voltage conductor of over 15,000,000 circular mills. This conductor cross section is more than 12 square inches. Because of the conductor size, the low voltage coils are designed with at least two conductors in parallel, each made up of many strands continuously transposed within the coil to keep eddy-current losses at a minimum and to keep the impedances of the several parallel paths equal. Figures 3 and 4 show a continuously transposed low voltage coil being wound. The

CONTINUOUSLY TRANSPOSED large cross-sectioned conductors made winding tedious. Paralleled stranded conductors were used. **(FIGURE 3)**



CIRCULAR SHAPED secondary coils eliminate sharp bends in coil construction, thus providing greater insulation strength. **(FIGURE 4)**





WIDE RANGE of secondary currents and voltages is obtained by connecting the primary in either delta or wye and by reconnecting phase windings by means of motor-operated tap changer. **(FIGURE 5)**

CORE AND COILS, cover and terminal board are assembled into single unit that can be tanked or untanked without disturbing internal connections. Unit is ready for final assembly. **(FIGURE 6)**

circular shape of these coils is an advantage over other coil shapes because it eliminates radial forces and insulating problems encountered at corners.

The high secondary current makes it impractical to bring the low voltage out in single leads, since the impedance of the leads would be as high as the impedance of the transformer itself. To overcome this problem, the low voltage leads are divided, formed, and interleaved to connect to a number of bus bars projecting through the cover. In addition, this interleaving minimizes the size of the cover opening and provides a means of bringing out the low voltage leads without excessive cover heating. Figure 5 shows the low voltage bus-bar connections of a transformer of this type. Figure 6 provides a good view of the low voltage side of the transformer, showing the interleaved connections.

Because the low voltage leads are brazed solidly to bus bars and the openings around the bars projecting through the cover are sealed, it is necessary to make the core and coils, the cover, and the terminal board a single assembly.

HEAVY SECONDARY TERMINALS are made up of a number of interleaving bus bars projected through the cover. The six primary bushings were mounted later. **(FIGURE 7)**

Four bolts fasten the transformer cover to the structural end frames, and lifting is done from lugs on the cover.

To provide tap voltages it is necessary to tap the high voltage winding, since both the few turns in the low voltage winding and the huge low voltage conductor make it impossible to tap the low voltage. In operation the voltage applied to the high voltage winding of the furnace transformer remains constant. The voltage applied to the furnace varies as the taps are changed. This means the unit has a variable volts-per-turn ratio. Therefore, a core was provided with a normal induction at the maximum volts-per-turn ratio. However, the unit will operate at a low induction on the taps which provide a low volts-per-turn ratio. Consequently, the core of a furnace transformer is not designed for performance at one optimum induction and is larger than is required on a normal power transformer.

The no-load tap changer provided for this unit is for external ground level and manual operation, with provision for interlocking with a circuit breaker. Also provided is a drum switch, geared to the tap changer handle for remote position indication.

To make possible a change from reduced capacity wye operation to full capacity delta operation, each end of each phase of the high voltage winding is brought out through a cover bushing. Figure 5 shows the external connections necessary for changing to wye or delta operation.

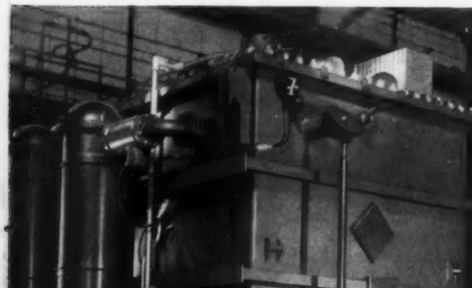
Due to the high ratio of primary to secondary voltage (80 to 1), protection of the transformer against switching surges is desirable. Modern lightning arresters having high discharge voltage ratings make this protection feasible. A 50-kv arrester will protect against switching surges on either the high voltage 44,000 wye or delta connection.

The temperature rise guarantee of 55 C over cooling water is met by providing forced-oil cooling. Since the unit is installed indoors, the high surrounding temperature is overcome by providing forced oil-to-water cooling. The availability of cooling water at furnace installations generally makes forced oil-to-water cooling most desirable. The two heat exchangers used on this unit are cylindrically shaped, two-pass, oil-to-water type, mounted in a vertical position. The cooler tubes are made of admiralty metal, the shell and baffles of steel, and the end bonnets of cast iron. The cooling water flows through the tubes, and the oil flows in the shell surrounding the tubes. A three-phase, totally enclosed motor with integrally mounted pump is provided to circulate the oil through each heat exchanger. Since the complete motor and pump unit is immersed in oil, there are no lubrication or stuffing box problems. Figures 7 and 8 show the pumps and heat exchangers mounted in position. Figure 9 shows the control diagram. A circuit breaker and a manual starting switch with thermal overloads are provided for starting and protection of each pump motor. The diagram also shows the no-load tap-changer interlock and drum switch.

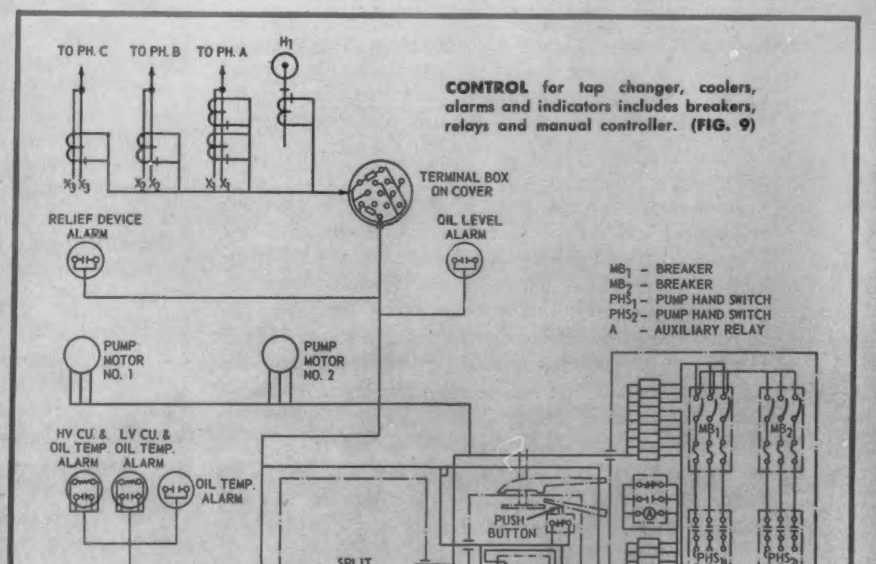
High efficiency provided

The larger core, extra copper weight in the form of bus bars, and the high short-circuit stress — all combine to make the unit heavier in order to maintain the same 99+ percent efficiency required in large power transformers.

The new high capacity furnace at Columbia with its large transformer will permit Shea Chemical Corporation to more than double its output of elemental phosphorus to meet corresponding increases in the expansion of the firm's sodium phosphate and phosphoric acid production facilities. The success of this transformer design shows that these large ratings are practical and point the way to similar installations in other chemical and steel industries.



TWO OIL-TO-WATER heat exchangers provide needed cooling. Totally enclosed motor with integrally mounted pump circulates oil through heat exchangers. **(FIG. 8)**



CONTROL for tap changer, coolers, alarms and indicators includes breakers, relays and manual controller. **(FIG. 9)**

ORAL COMMUNICATION—an important part of engineer's daily life

by **RALPH GRUTSCH**
Washington District Office
and
HERBERT E. PRITZLAFF
Milwaukee District Office
Allis-Chalmers Mfg. Co.

IN THEIR CEASELESS EFFORTS to produce more and better products at lowest possible cost, engineers are constantly improving the productive machinery essential to better living. The stories of how these engineering improvements were accomplished are told in engineering society papers, in articles throughout the technical press and in other types of literature.

However, during the period when differing engineering approaches and various pieces of equipment are being evaluated, the oral word — not the written word — is the method of expression that guides the rapid understanding of related drawings, specifications and other data. The amount of engineering time required for any given job in this day of complex engineering projects is dependent, to a large extent, on the ability of engineers to exchange their ideas clearly, precisely and quickly.

To help young graduate engineers develop their ability to communicate engineering ideas orally, a part-time course within the framework of the Graduate Training Program* was established some years ago. Consisting of 26 half-day meetings, this course is based on the premise that the ability to talk concisely and convincingly on a technical subject can be gained only through participation-type training.

Course designed to develop self-reliance

Since engineers normally use blueprints, mathematical symbols, and models or samples in conveying their ideas, the use of pictures, drawings, data, charts, and other appropriate visual aids is encouraged. All members of the company's Graduate Training Program are encouraged to take this course. Special emphasis is directed toward young engineers planning sales or application careers, since the specific and detailed engineering information necessary to determine how one company's product can fit into another company's plans must be interpreted and given direction orally. Some of the sessions are arranged to fit the specific needs of this latter group.

While this course is designed primarily to accustom young engineers to talk about the products with which they are concerned, important by-products result. For example, subject knowledge is obviously essential to any convincing presentation. To simplify the problem of becoming expert, each individual presentation is confined to a single subject facet and presentations are held to 10 minutes. Assignments for each session are made the previous weeks so that each member of the class will have ample time to prepare himself.

At the time assignments are made, sources of information are supplied to each class member scheduled for a

*"The Guided Self-Development of Engineers," Paul Nippes and W. Margopoulos, Allis-Chalmers *Electrical Review*, 3rd Quarter, 1956.

TYPICAL SCHEDULE FOR ONE CLASS SESSION
MEETING 17, SWITCHGEAR

8:30	Introduction
8:35	Slidefilm
8:55	Good Points ?
9:00	Product Speaker
9:10	Questions ?
9:15	4-kv Metal-Clad Switchgear
9:25	Well clad ?
9:30	4-kv and 15-kv Air Magnetic Breakers
9:40	Magnetic Talk ?
9:45	15-kv Metal-Clad Switchgear
9:55	15-kv Speaker ?
10:00	Safety Interlocks on Metal-Clad Switchgear
10:10	Safe or Out ?
10:15	Break
10:25	Movie
10:55	Discussion
11:05	*Pneu-Draulic* Emergency Closer
11:15	Fast ?
11:20	New Low Voltage Breakers
11:30	Good Voltage ?
11:35	New Low Voltage Structures
11:45	Strong ?
11:50	Sales Skit
12:00	Next Move ?
12:05	Competition
12:15	Ahead ?
12:20	Program Summary and Trophy Presentation

TYPICAL TECHNICAL INFORMATION INTERVIEW GUIDE

Subject	Engineer	Course Member
4-kv Metal-Clad Switchgear	D. C. Burk	Jim Quinn
4-kv and 15-kv Air Magnetic Breakers	J. A. Keymar	Dan Clasen
15-kv Metal-Clad Switchgear	L. R. Poker	Ray Bilancia
Safety Interlocks on Metal-Clad Gear	E. R. Brucklacher	Tom Hitzman
Pneu-Draulic Emergency Closer	R. F. Tucker	Mahlon Brock-lehurst
New Low Voltage Breakers	D. C. Klein	Jerry Smith
New Low Voltage Structures	Frank Nolan	John Townsend

FACILITY IN ORAL COMMUNICATION comes through planning and practice.

presentation. To help him gain confidence and self-reliance, he is required to make his own arrangements for fact-finding interviews, which are an important part of his technical source material. These interviews in themselves afford practice in oral communication of engineering ideas.

When an engineer is contacted by a designated class member, he offers whatever guidance he can and suggests additional source material. Interviews are timed for their mutual convenience. Both must sandwich these discussions into regular work schedules.

In preparing their presentations, the young engineers learn the truth of the adage that a teacher learns more than his students do. Considerably more information than can possibly be used must be gathered and evaluated. Methods of presentation must be considered. The use of visual aids must be determined on the basis of what is available, the subject matter being discussed, and the size of the group. For example, a blueprint would be appropriate for a group of three or four people, but a projected slide would be more appropriate if a dozen or more men are involved.

A general guide to selection of appropriate visual aids is given on the following page. Class members soon realize, however, that no hard and fast rules are possible.

Group Size					Visual Aid	Information										
2-5	5-10	10-15	15-20	Over 20		Curves & Graphs	Diagrams & Charts	Sketches & Outlines	Equation Development	Theory Development	How to	Physical Features	Listings & Tables	Pictures	Appearance	Internal Construction
X					Blueprints							X			X	X
X	X				Flip Charts	X	X	X	X	X	X	X	X	X	X	X
X					Slide Viewers						X	X		X	X	
X					Photographic Prints	X	X				X			X	X	
X	X				Bulletins	X	X	X	X	X	X	X	X	X	X	X
X					Samples							X			X	
					Scale Models							X			X	
X	X	X			Cutaway Models							X			X	X
	X	X	X		Posters & Cards	X	X	X	X	X	X	X	X	X	X	X
	X	X	X	X	Blackboard			X	X	X			X			X
		X	X	X	Flannel Board	X	X		X	X			X			
					Projectors											
		X	X	X	Slide (Silent)	X	X				X	X		X	X	
			X	X	Slide (Sound)	X	X			X	X	X		X	X	
	X	X	X	X	Overhead	X	X	X	X	X		X				
	X	X	X	X	Opaque	X	X					X		X	X	
			X	X	Movie	X	X	X	X	X	X	X	X	X	X	X

While this guide is based on accepted practice, extremely effective presentations have been made using visual aids in ways quite different from those indicated.

Visual aids, to be most effective, must become almost an extension of the individual making the presentation. For example, a discussion of motor bearing design would logically lead into the use of drawings, pictures, models, cutaways or some other device that shows the features and advantages of the particular design being discussed. From the various devices available, each person is encouraged to select those easiest for him to use effectively.

Recognition of the need for naturalness in the oral communication of ideas is basic to this entire training course. No effort is made to fit everyone into a stereotyped pattern. Rather, every effort is made to have each person evaluate his own individual talents, abilities, and mannerisms so that his presentations of engineering ideas will be more effective because they reflect his personality.

Since it is often required that men think in terms of unexpected problems during engineering discussions, the development of presentation techniques that are natural to each individual is essential. Otherwise, questions or criticisms might cause him to lose his composure.

Communication techniques depend on personality

Consequently, a major purpose of the course is to present a "smorgasbord of sales presentation ideas." Each individual selects those that are most suitable to his abilities and personality. He then develops these techniques.

First in importance in any presentation, he learns quickly, is to gain and hold the attention of his audience. This is especially true for the young engineer planning a career in sales. He learns that in sales situations the customer is frequently preoccupied with urgent matters of the moment — often indifferent, even anxious for the sales engineer to leave.

Consequently in this course, unlike undergraduate classes in which the professor demands attention, the individual making each presentation must win attention. He must express his ideas in a manner that is sufficiently interesting to hold the attention of his audience. Regardless of how much he knows — only that portion of his message that is listened to can possibly make an impression.

Techniques that gain and hold attention are discussed. For example, class members learn that "for instance" is an expression that frequently has almost magical power. This phrase grasps the audience's attention and prepares it for a specific example to prove a point that may have been somewhat ambiguous. Most people find the concrete, specific examples worthy of their attention. The value of humorous stories in breaking down barriers to easy communication is pointed out. However, if humorous stories are inconsistent with an individual's personality, he is advised against using them. Stories and examples relevant to the subject are always valuable in heightening interest. They do not need to be humorous.

After each presentation a critique is held. An evaluation is made of the speaker's use of visual aids and his coverage of the assigned topic. These critiques provide the material each class member needs to evaluate himself and his abilities in the use of available tools for the communication of engineering ideas. He learns to evaluate himself objectively. He learns to know himself as others see him. With this knowledge, he can either shore up his weak spots or rationalize them away, thus gaining a poised, confident composure. He learns to build on his strong points.

Course organization provides broad base

Program topics, listed on page 17, are selected to cover a wide range of subjects. Products, industries and company organization are discussed. The value of Moody's Industrials, Poor's List of Directors, Dun and Bradstreet and other industrial directories is considered. Also discussed is the place in industry of the various trade associations as well as professional and technical societies.

Each class session begins with a slidefilm on some aspect of salesmanship or human relations. Also, during each session, a movie covering some particular industry or process is shown and discussed briefly. This serves the dual purpose of providing a change in pace during the session while broadening the students' industrial knowledge.

The importance of economics in engineering decisions is brought out through discussions of equipment applications. An appreciation for the need of "dependability first" in continuous processing plants obviously calls for top quality equipment. On the other hand, low initial cost may be the prime consideration for equipment that is used to perform only secondary functions on rare occasions.

PROGRAM TOPICS

1. Pumps
2. Electrical Control
3. Large Motors
4. Circuit Breakers
5. Advertising
6. Couplings, Seals, and Bearings
7. Power Transformers and Regulators
8. Steel Industry
9. Crushers
10. Hydraulic Turbines
11. Screens
12. Generators
13. Systems and Procedures
14. Boiler Feed Pumps
15. Induction Heating
16. Company Organization and Business References
17. Small Motors
18. Switchgear
19. Steam Turbines
20. Rectifiers and DC Power
21. Network and Distribution Transformers
22. Condensers (Steam)
23. Compressors
24. Exciters, Regulators, DC Generators
25. Water Conditioning
26. Grain and Chemical Equipment
27. Distributor Sales and Company Policy
28. Substations

From application discussions, sessions devoted to products gain added significance, especially for the young engineer planning a sales career. He learns how features of one product make it the best possible unit for certain applications — but not so suitable for others. This, in turn, leads logically into that part of many sessions called the "Impromptu."

Get all the information

Primary purpose of the Impromptu is to remind the class that when they are after information they should get all that is available. If concerned with design, the engineer must know what problems are involved and all the details of the job that must be done before he can design a suitable product.

If concerned with application, the requirements imposed by ambient conditions, load characteristics, duty cycles and numerous other considerations must be determined before the most suitable equipment can be selected.

If the young engineers are concerned with product sales, the Impromptu points up the importance of learning the prospect's problems and plans. Industrial products are bought because of a need. What is that need? Don't waste time discussing features in which there is no interest. Learn the need, then concentrate on the specific features that answer that need. Does he need a unit to replace a piece of equipment that is unsatisfactory? If so, why is it unsatisfactory? Is he planning a modernization program to increase plant efficiency? Does he need the equipment now, next month, or next year? Are weight, space, noise, or appearance important? How many does he need? Only after learning his prospect's problems and plans can the sales engineer determine how his products can best fill those needs.

In the Impromptu, one trainee takes the part of a buyer, another takes the part of a sales engineer who is making a cold call. The one taking the part of the buyer has been previously briefed. The other has the problem of learning the need, the equipment required to fill that need, and all pertinent information having anything to do with the application.

The entire skit develops extemporaneously, with the sales engineer asking leading questions in his efforts to understand the particular technical problems and personal preferences that will influence the final decision. "How can the products I have to offer best serve his needs?" is the underlying philosophy of the sales engineer throughout the skit.

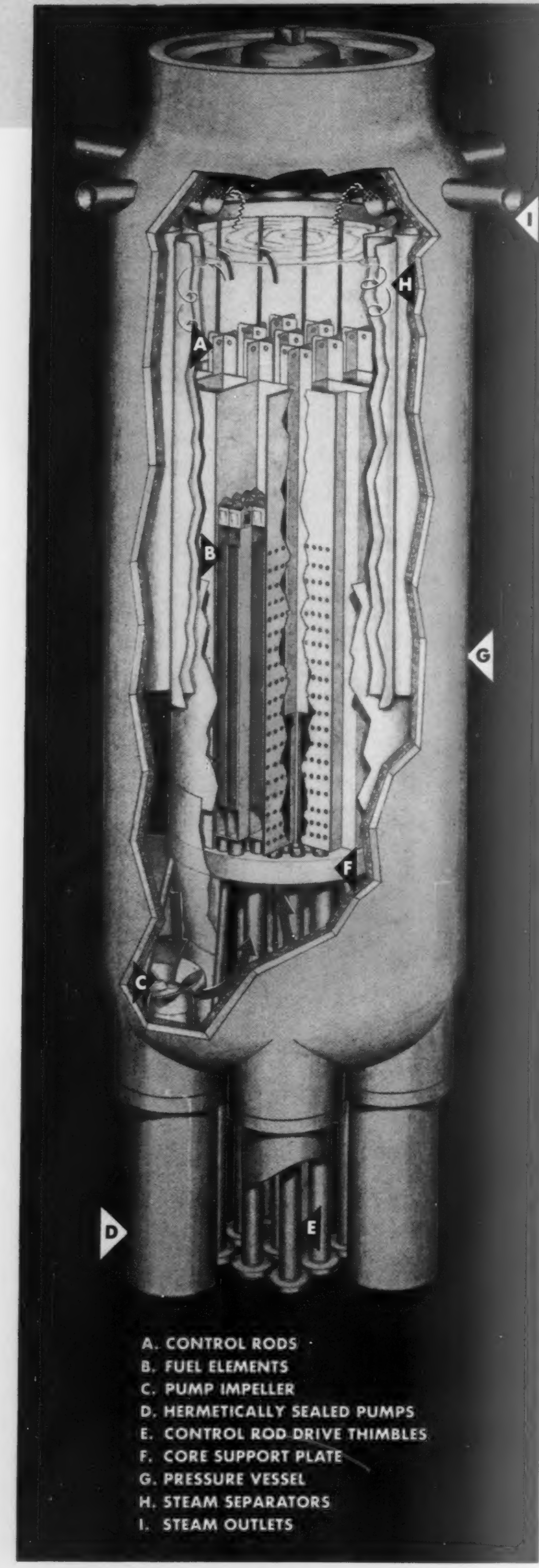
In these skits, as in other presentations, mistakes are expected. However, through his mistakes and the evaluations that follow, each trainee gains experience. He learns by doing. He acquires competence in the shortest possible time with the least possible embarrassment to himself and others.

Similar to the Impromptu is a presentation called the "Sales Skit." However, the Sales Skit is not extemporaneous and is usually based on records from the company's files of actual problems encountered in the sales and application of its products. They can be technical, commercial, or psychological. The young engineers participating in the skit are notified a week in advance and have adequate time to prepare themselves. In this way, every one in the class session is able to observe how a specific sales situation was resolved.

The variety and magnitude of engineering problems solved by industry today require that many men work together. The rapid and accurate exchange of engineering ideas and data is imperative if the efforts of all the men working on a project are to be properly coordinated and the individual efforts resolved into a unified solution.

NEW LIGHT ON OUTDOOR POWER — **Recent Florida Power & Light Company station at Palatka, Florida, takes full advantage of modern weatherproof steam turbine-generator unit design. Steam valves are sheltered below the turbine deck. Motors and pumps are located adjacent to the outdoor boiler and below the turbine deck, while station switchgear and power transformers are out in the open.**
Allis-Chalmers Staff Photo by M. Durante

ADVANCED TYPE Boiling Reactor Plant Will Generate 60,000 Kw



LARGE recirculating water pumps greatly increase reactor capacity and provide control of nuclear reaction. **(FIGURE 1)**

by C. B. GRAHAM
Chief Engineer
Nuclear Power Division
Allis-Chalmers Mfg. Co.

New control of nuclear reaction will be gained by varying the rate of water recirculation through the reactor.

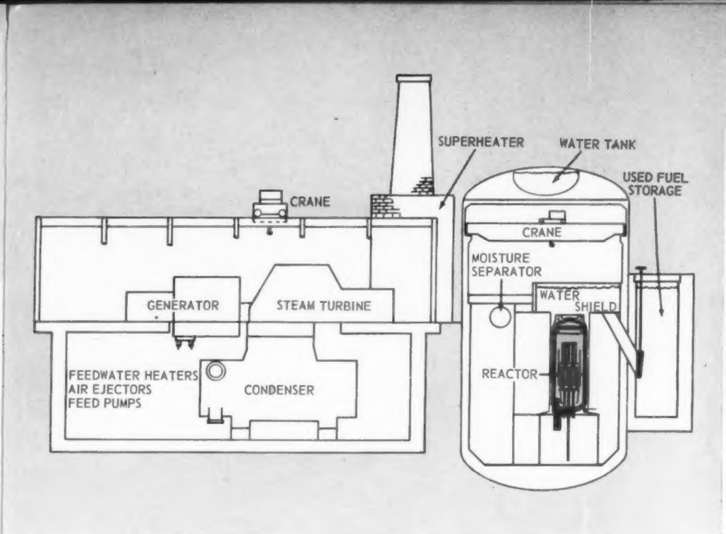
ALMOST COINCIDENT with the formal dedication of the Experimental Boiling Water Reactor at Argonne National Laboratory, plans for construction of a full-scale nuclear fueled power plant of advanced boiling water reactor design were announced by a group of Midwest utility companies. Construction of the plant is to be completed by 1962. This controlled recirculation boiling reactor, known as CRBR, will be located on a site yet to be chosen on the Northern States Power Company system subject to Atomic Energy Commission approval.

Knowledge and experience gained in the development, design and operation of the EBWR facility have made possible a dramatic increase in reactor efficiency without sacrifice of the high degree of safety demonstrated by the Argonne unit. With only a slight increase in reactor size over the 5000-kw Argonne unit, the new unit will supply the steam for a 60,000-kw turbine.

The reactor's cylindrical core, measuring five feet by five feet, will generate as much heat — 157.3 megawatts — as a boiler burning about 20 tons of coal per hour. This high energy output per unit of volume is possible because of the large volume of water being recirculated continuously through the reactor.

The reactor vessel, shown in Figure 1, will be 9 feet in diameter and 23 feet high. It will be housed in a steel and concrete building approximately 45 feet in diameter and 70 feet high. Reactor power output will be adjusted by controlling the rate of water being recirculated through the reactor core. Pumps located at the bottom of the reactor circulate the water which carries along steam produced by the heat of the nuclear reaction. Steam bubbles are then separated by centrifugal devices.

Water in the core region of the boiling water reactor slows down neutrons to low velocities at which the probability of a neutron-uranium reaction (fission) is much greater. Increased amounts of steam in the water reduce this slowing-down or moderating effect of the water and tend to shut down the reactor unless compensated for by other means. With natural circulation, the core size for 157.3 mw of heat would be quite large. By forcing the steam bubbles out of the core and bringing in water at a high rate, the performance of the core is markedly in-



SMALL BY COMPARISON with its 60,000-kw turbine-generator and condenser, the reactor supplies 157.3 mw of heat. **(FIGURE 2)**

CRBR DATA

Capacity	60,000 kw
Steam pressure, turbine inlet	540 psig
Steam temperature, turbine inlet	825 F
Feedwater temperature	300 F
Steam flow	572,500 lb/hr
REACTOR	
Power (heat)	157.3 mw
Core diameter	5 ft
Core length	5 ft
Reactor vessel height	23 ft
Reactor vessel diameter	9 ft
Steam pressure	600 psig
Steam temperature	489 F
Other Data:	
Superheater power (heat)	38 mw
Reactor building diameter	45 ft
Reactor building height	70 ft

creased and high power is permissible even in a relatively small reactor.

If an increase in steam is required from the reactor, the speed of the recirculating water pumps is increased automatically. The increase in water velocity increases the nuclear reaction, thereby creating more steam for the turbine.

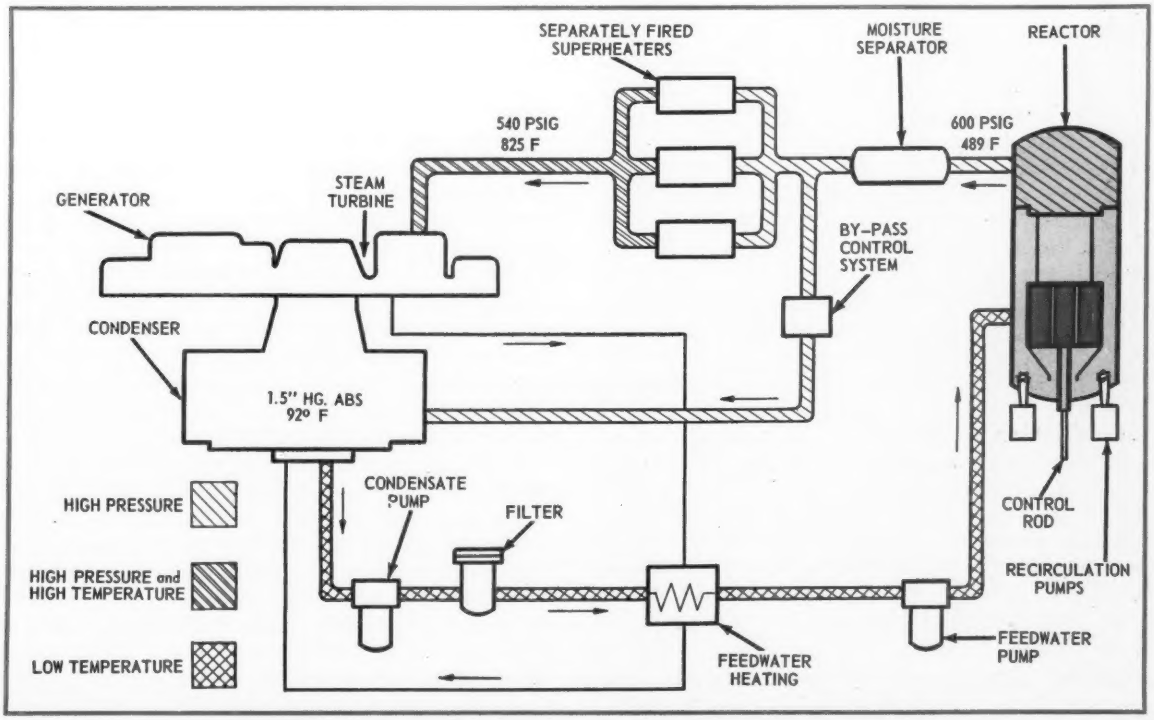
If a decrease in steam is required, the pump motors are slowed down to reduce the quantity of steam removed from the reactor core, thus slowing down the reaction. Pump power is a small portion of the plant power.

The control rods in the reactor are used only for rough control or for shutdown in emergencies.

The reactor will supply saturated steam at 600 pounds per square inch pressure gage and 489 F, as shown in Figure 3. Steam will flow through separately fired superheaters directly to the turbine. The superheaters, which will be fired with conventional fuel, will increase the temperature of the steam to 825 F at 540 pounds per square inch gage.

The steam turbine will be similar to the Argonne unit but with much greater capacity. The slightly radioactive steam flowing through the turbine will be sealed in by special seals on the turbine shaft.

After the energy in the steam is utilized in driving the turbine-generator unit, the exhaust steam is condensed and returned to the reactor to be used again. A scale diagram of the plant is shown in Figure 2.



SEPARATELY FIRED SUPERHEATERS will raise the steam temperature to a value consistent with standard turbine designs. Condensate water is returned to be recycled through the reactor. **(FIG. 3)**

Digital Computer SPEEDS Transformer Design


by **C. P. KAPPELER**
and
E. A. GOODMAN
Allis-Chalmers Mfg. Co.
Pittsburgh Works

SOLVING DESIGN PROBLEMS faster, the digital computer enables the engineer to make a more thorough analysis. **(FIGURE 1)**

New computer equipment enables the engineer to select optimum distribution transformer design in less time.

DISTRIBUTION TRANSFORMERS are manufactured in standard voltages and kva ratings; they are not usually designed individually but in pilot lines of basic stock transformers. Their design is, therefore, well suited to computer programming.

There are several reasons for a continuing redesign program of distribution transformers, such as new construction methods, new materials, or a change in performance or dimensional requirements. When a change is required, a whole new line is designed as a single project. For this reason, a large number of repetitive calculations have always been necessary. To complete such a project, certain parameters must be varied until an improved design is obtained. In the past, the engineer found it necessary to make three, four, or a dozen design attempts for each size, depending on his ability to sense from his first trials how far he should go in a particular direction.

While this system of transformer design has been workable, it has one basic flaw: the design obtained may not have the most economical combination of parameters for acceptable transformer characteristics. Unfortunately, it is too time consuming to search for the most economical combination, because the number of possible designs is practically unlimited. Actually, it is physically impossible for one engineer to consider all possible designs and select the most economical. Therefore, in the past, engineers were forced to settle for an improved design, although they realized that a more economical design probably existed.

The basic calculations used to design a distribution transformer of a given size, voltage, and core and coil construction involve about 100 relatively simple equations requiring only arithmetic operations. Most of these equations use quantities obtained from established equations, constants, and other data. In effect, then, a complete design of a given distribution transformer is a series of about 100 simultaneous equations involving about as many unknown quantities. However, most of these equations contain only a few unknowns, with the longest containing about 20 unknowns and constants. Since most of the unknowns in this series of equations are functions of other unknowns and constants, they are not independently variable quantities.

We can obtain by substitution a huge equation which contains only ten independent variables and a sizable number of constants. Fortunately, nine of these ten independent variables are not continuous functions and, for practical design purposes, can only assume a limited number of values. As an example, the number of layers of wire in the low voltage winding must be an even integer.

The tenth independent variable, the flux density in the core steel, can assume an infinity of values between maximum and minimum limits. The designer can come reasonably close to the most desirable design, however, by letting the flux density vary in steps between those limits.

It is quite evident that even if each of these independent variables can assume only a small number of values, the total number of possible, though not necessarily acceptable, solutions is large. For instance, even though the number of different values for the flux density might be limited to four, we still have to make several million design attempts in order to arrive at the optimum solution for a typical 25-kva transformer. The number of theoretically possible designs increases with transformer size.

TABLE I	
CHARACTERISTICS of 10-kva, 2400—240/480 volt computer designed distribution transformer in percent of previous stock design	
Weight of Copper	82%
Weight of Core Steel	106%
Weight of Total Active Material	96%
Percent Impedance	90%
Total Loss	100%
Total Weight	95%

The final choice as to which of these alternate designs is the most desirable must always be left to the engineer, who will base that decision on considerations of user preference, product appearance, operating characteristics, cost, and product standardization.

The first step in the program was to recognize that the design could be expressed as a function of only ten variables. Designers normally solve each of the 100 equations individually, but because of the complexity of the complete equations designers never found it necessary to express this equation as a whole. Analysis of the program by a mathematician resulted in the conversion of curves and tables to equation form which is the necessary input for any computer. It was discovered that certain of our unknowns were dependent rather than independent variables.

Computer choice depends on limits of variables

A small computer can be used if the engineer assigns fixed values to a number of the independent variables, so that the computer need only supply a limited number of solutions.

In the solution of a distribution transformer problem the primary object of using a digital computer such as the IBM "650" shown in Figure 1 is to find the best possible design for a piece of electrical equipment with rigidly defined characteristics and limitations. Even though it will take this computer considerable time to make the necessary design attempts, this time is well justified. Even the IBM "650" computer could not cover all the variables completely in a reasonable time, so the program was re-examined for further limitations which might be applied to reflect standard shop practice and material stocking problems. For example, the core steel width was either made constant for the whole problem, or varied only in a few specific steps, even though it is one of our ten independent variables.

An important advantage of the IBM "650" computer in solving this type of problem is its ability to compare a calculated value to another fixed number, and on the basis of this comparison, to automatically accept or reject it. For example, the core losses of the transformer should not exceed a fixed guarantee value; any design attempt which does not meet or better this guarantee is rejected by the computer. If this happens, the machine does not complete the calculation but proceeds to the next design attempt. The insertion of about a dozen rejection criteria in the program eliminates a large number of unacceptable theoretical designs. If the rejection criteria are placed near the beginning of the program, considerable computer time is saved. Figure 2 shows a schematic chart of the sequence of calculations and rejection criteria.

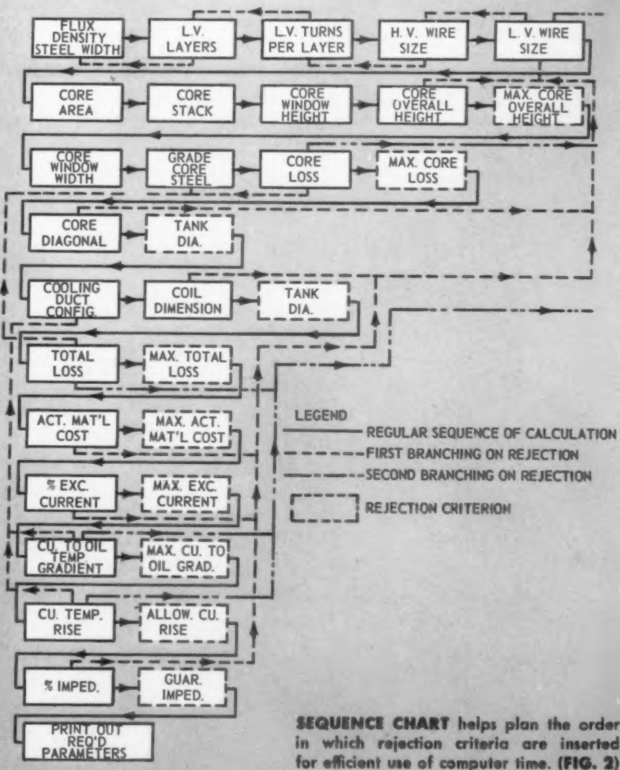
The whole program for a 10-kva transformer required 1616 computer addresses, out of the 2000 available on the drum; when an acceptable design was completed, 64 quantities were printed out.

As an example of the type of equation encountered, Figure 3 illustrates part of the calculations required for the cooling ducts shown in Figure 5.

Engineering skill still needed

Obviously, in a problem such as this, the more skilled the engineer who sets up the program, the better the results. He must assign values to certain variables and establish limits for others. He must allow sufficient variation for the computer to cover the problem successfully without wasting its time. His judgment and experience can be transmitted to the machine only to the degree that he can express them mathematically.

Computer calculations for each acceptable design are quite exhaustive and provide a meticulously calculated



SEQUENCE CHART helps plan the order in which rejection criteria are inserted for efficient use of computer time. (FIG. 2)

$$\sigma_l = 4N e_{2t} T(Y - \tfrac{1}{2}q_1 + 1) + e_{2t} T [L + \pi d - 2(b + 3)]$$

$$K = \frac{W_{FC}}{713.6}$$

$$\theta_{to} = 55K^{0.8}$$

$$\theta_o = .92\theta_{to}$$

$$U_l = \frac{W_{FCl}}{\sigma_l}(17.5 - 0.1\,\theta_o)$$

$$\text{MAX. } (U_h, U_l) \leqslant 10 \text{ (rejection criterion)}$$

LEGEND

σ_l = area of low voltage winding available for cooling.

N = number of layers of narrow end cooling sticks.

e_{21} = width of each turn of wire.

T = number of turns of wire per layer.

Y = narrow end mould width.

q_1 = number of sticks per narrow end.

L = mean turn length.

d = average thickness of winding.

b = width of core steel.

K = cooling ratio.

W_{FCl} = total losses of transformer low voltage winding.

θ = oil temperature.

U_l = low voltage copper to oil temperature gradient.

U_h = high voltage copper to oil temperature gradient.

W_{FC} = total losses of transformer.

EQUATIONS determine part of coil geometry. This is a sample of many such equations used in designing a transformer. **(FIG. 3)**

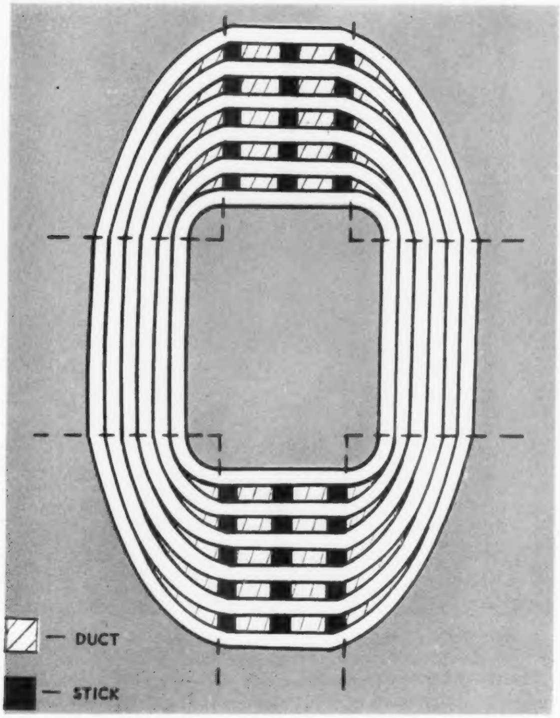
answer for every quantity involved. As an example, a designer would be reasonably sure that a certain number of cooling ducts in the transformer winding would not provide adequate cooling and therefore he would not even attempt to calculate such a design. The digital computer, on the other hand, must calculate the copper-to-oil temperature gradient. If this gradient exceeds the maximum permissible value, the computer rejects that design and proceeds to the next cooling duct configuration. As a result, a combination which a designer would reject intuitively would be worked out by the computer and analytically accepted or rejected.

A design engineer need not have any knowledge of the mechanics of the machine's operation. A computer specialist can translate the equations and tables set up by the engineer into the punched card language of the computer. The results are printed out in a manner that the engineer can easily interpret.

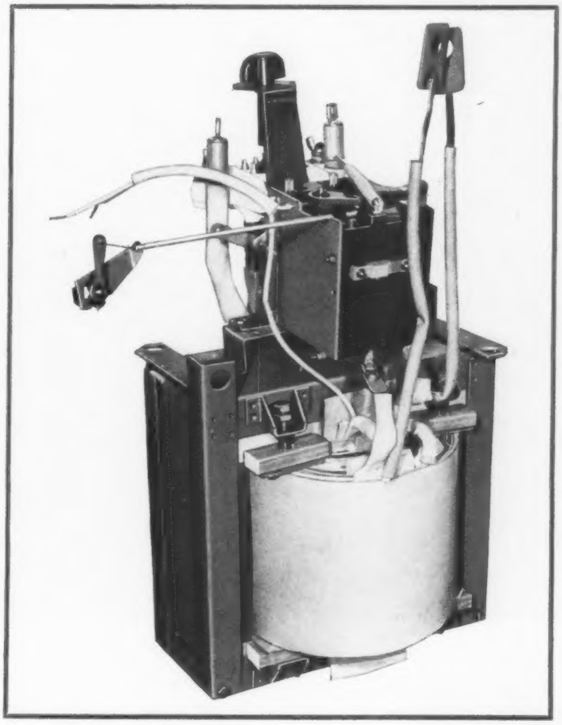
Results show better balanced designs

Computer results for a 10-kva, 2400—240/480-volt transformer are impressive. The computer attempted a large number of theoretical designs, most of which it rejected because they did not meet all the rejection criteria. The machine also completed and printed out 108 acceptable designs which were then reviewed by engineers on the basis of their various merits. As a result of this investigation a redesigned transformer has been built and tested. Figure 6 shows the core and coil assembly of this transformer before tanking. The performance and other characteristics of this 10-kva unit are at least equal to, or better than, those of previous designs. In Table I the characteristics of this transformer and of the old design are compared. The weight of the copper and electrical steel was reduced by 9.8 percent, the total transformer weight by 5 percent, and the transformer impedance by 10 percent.

DISTRIBUTION TRANSFORMERS are designed as a whole line of basic stock units like these single-phase units, rated 5 to 50 kva, 12,000-120/240 volts, 60 cycle, 55 C rise. **(FIGURE 4)**



COOLING DUCTS are obtained by placing spacing sticks between winding layers. Their effectiveness can be computed. **(FIGURE 5)**



COMPUTER-DESIGNED, this 10-kva distribution transformer will weigh less and show improved characteristics. **(FIGURE 6)**

These reductions were not obtained by lowering the quality of the product in any way, but by more efficient use of all the components that constitute the electromagnetic circuit of the transformer. Obviously, then, the material savings in these transformers alone justify the use of the computer, and the design is the basis for a new line of stock transformers.

Various programs for larger distribution transformer designs are in process, with an ultimate goal of all standard designs being based on computer calculations. Due to changing market conditions, variation in copper and steel prices, as well as changes in performance requirements, there will be a continuing need for new computer designs. In recent years, stock transformer lines have been revised every two or three years, representing many man-hours of work. Once the program has been set up for a computer, new designs can be obtained to meet new conditions by merely changing a few punched cards.

The advantages of using a large digital computer for an exhaustive study and complete solution of a distribution transformer design problem are:

1. The computer design more nearly approaches the optimum acceptable design.

2. A calculated value for every pertinent quantity involved is obtained for every possible acceptable design; the decision as to which design is most desirable is left to the engineer.

3. Any one of the constants of the computer program can be easily and quickly changed, and the program re-run.

4. The transformer can be designed more closely and quickly to fill specific user requirements by changing one or more of the rejection criteria of the program.

5. The boring routine mental labor of repetitive longhand and slide rule calculations required by a number of design attempts is eliminated.

6. The computer program can be assembled in a reasonable period of time and involves only relatively simple equations.

7. The engineer has more time available for creative efforts.

8. The availability of the complex computer equipment also enables engineers to work out special problems involving the application of the transformers to any particular distribution system.

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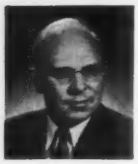
STARTING with SLIP RINGS SHORTED

PROPERLY APPLIED wound-rotor motors, such as this 700-hp rod rolling mill drive motor, offer high starting torque and speed control; but secondary (rotor) control is required. **(FIGURE 1)**



by R. C. MOORE
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Allis-Chalmers Mfg. Co.

You might wish to substitute a wound-rotor motor for a cage motor. Merely shorting the slip rings may not work.

"WHY CAN'T WE SHORT-CIRCUIT the slip rings and start it across the line like a squirrel-cage motor?" is a question frequently asked about wound-rotor induction motors. This question is especially pertinent when a motor is being re-applied, if control components or resistor elements are in poor condition and no replacements are in stock, or if the space occupied by the resistor elements is desired for some other purpose.

Knowing that wound-rotor motors are designed for external resistance in the rotor circuit, the person asking this question is usually apprehensive about the effect of full-voltage starting on the insulated rotor winding.

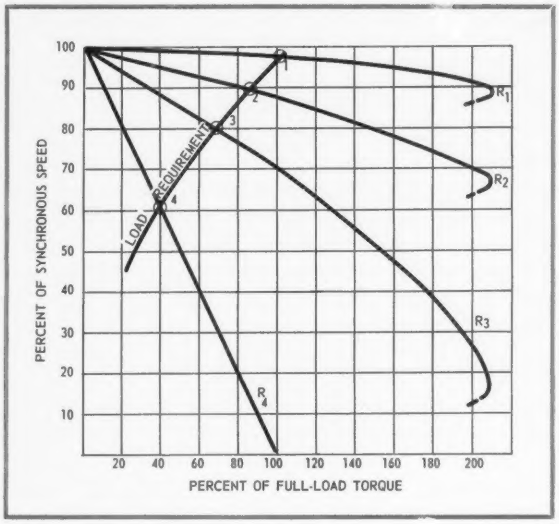
Motor characteristics must be considered

Fundamental to an adequate answer is an appreciation of wound-rotor motor characteristics. The wound-rotor motor was developed initially to fulfill the need for a relatively simple type alternating-current motor that could provide either variable speed, or relatively high starting torque with low starting current, or both. These characteristics are not available in the squirrel-cage motor. To obtain them in the wound-rotor motor, resistance must be inserted in the rotor circuit.

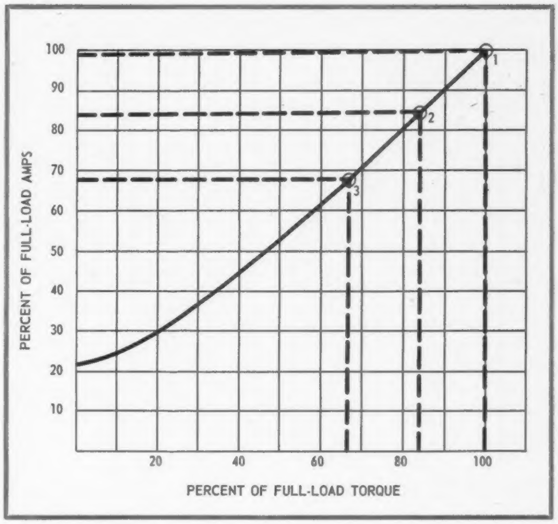
For a given required load torque, the amount of speed variation possible will depend on the amount of resistance inserted in the rotor external circuit. In Figure 2 a speed-torque curve is plotted for each of four different resistance values. To operate a wound-rotor motor and its connected load at different speeds, the rotor resistance is varied. Operation at various speeds is indicated in Figure 2 by the points at which the load requirement curve intersects the motor-torque curves. Intersection point 1 shows the full-load torque value with zero external rotor resistance. Corresponding current points for the various motor speed points given in Figure 2 are shown in Figure 3.

An item of particular interest concerns operation at constant load torque and variable speed. In these applications, if the torque stays constant, the motor current stays constant, even though the speed is varied by changing the rotor external resistance. For example, in an application requiring the motor to operate at constant torque over a range of different speeds, the motor current does not change but remains constant. Even at standstill, with resistance R_4 in the external circuit of the rotor, the motor develops full-load torque and takes only full-load current from the line.

If speed control is not desired after the load has been accelerated, a wound-rotor motor can be operated at full speed with its slip rings short-circuited. It will carry its rated load in the same manner as a squirrel-cage motor. There is, of course, nothing wrong with this method of operation.



WOUND-ROTOR MOTORS are operated with slip rings shorted at rated speed. Speed and torque decrease when the secondary resistance is increased by adding external resistors. **(FIGURE 2)**



MOTOR CURRENT decreases when speed and torque are reduced by adding external resistance to the motor secondary circuit. Points 1, 2 and 3 correspond to points indicated on Figure 2. **(FIGURE 3)**

The effects of short-circuiting the slip rings while bringing a wound-rotor motor up to speed can be best appreciated by comparing the wound-rotor motor to its close relative, the cage-type induction motor.

Wound rotor characteristics are different

Both squirrel-cage and wound-rotor induction motors frequently have the same type stator, but the rotor windings are different in practically every respect. Some of the differences are revealed when the two types are compared. The two types are shown side by side in Figure 4.

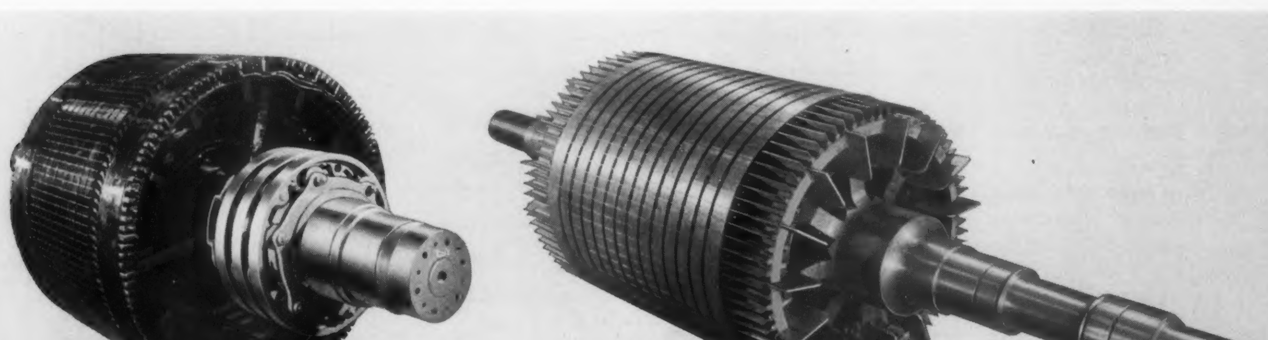
Squirrel-cage rotors have uninsulated bars in direct contact with the steel laminations of the core. The ends of the cage bars, or rods, as they are sometimes called, are short-circuited at each end of the rotor by short-circuiting rings.

However, in the phase-wound rotor, conductors in the rotor slots are insulated from one another and from ground. Besides, the bar ends are not short-circuited as in the cage type. Instead, they are connected electrically in essentially the same way as is the stator winding. In this type winding, the current flows from slip ring to slip ring through series-connected conductors. The rotor winding currents and their paths are therefore different from those in the cage-type rotor.

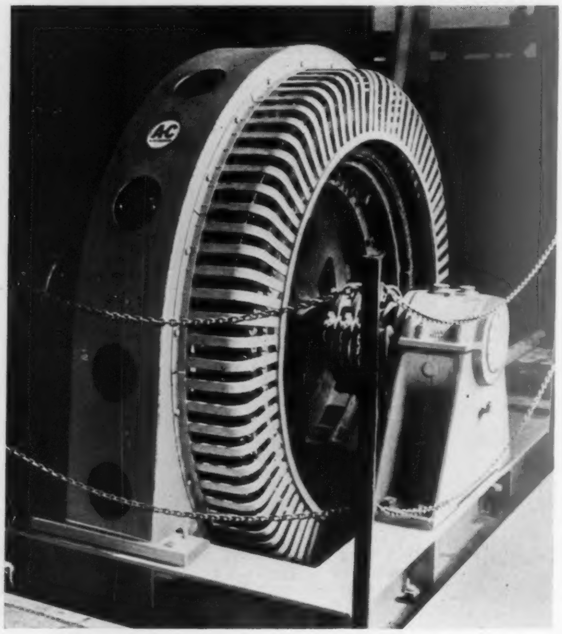
Other differences also exist. For example, a phase-wound rotor must have a winding connected for the same number of poles as the motor's stator winding. By contrast, voltages and currents in a cage rotor will adjust themselves automatically to the stator pole connections.

Another difference between the two types of rotors is the number of phases each winding has. A squirrel-cage rotor can be shown to have a number of phases equal to the bars per pair of poles. On the other hand, in the phase-wound rotor, the number of phases is not determined by the slots per pair of poles but by the winding connection. Usually, the insulated rotor winding is connected three phase.

These and other differences between cage and phase-wound rotor windings are indicative of dissimilar starting characteristics. These characteristics are important considerations when determining if a wound-rotor motor can be started with the slip rings short-circuited.



WOUND ROTOR (left) has windings brought out to slip rings. Cage type (right) needs no rings. **(FIGURE 4)**



LARGE WOUND-ROTOR motors, such as this 1000-hp induced draft fan drive, cannot be safely started with rings shorted. **(FIGURE 5)**

Starting currents can be appreciable

If started with the slip rings shorted, small low speed wound-rotor motors will usually have lower inrush currents than the same size cage motors. The curves of Figure 6 show locked-current data for two motors, a cage type and a wound-rotor type. The two motors have identical stators and stator windings. High speed motors, on the other hand, have inherently lower reactance than low speed machines and correspondingly higher starting currents.

In the design of cage-type high speed, across-the-line start motors, more than the normal inherent reactance is often "built in" to keep the motor starting current from becoming too high. After a cage motor is built, there are no rotor terminals to adjust the motor impedance for purposes of influencing the starting current.

In the wound-rotor motor, however, current limiting is done entirely by inserting resistance in the rotor circuit. Consequently, it is not necessary to build in extra reactance.

For this reason, high speed wound-rotor motors with shorted slip rings will frequently have larger locked-rotor currents than cage motors of the same size. Figure 7 compares the starting currents of high speed cage and wound-rotor motors of the same size. Slip rings of the wound-rotor motor were shorted.

Large starting currents can be harmful

Even if system supply can tolerate the large starting currents indicated in Figure 7, many other considerations are involved. Because of poor locked-rotor and accelerating torques delivered by a wound-rotor motor with shorted rings, the large stator and rotor currents may flow for a considerable length of time. This is especially true when attempting to start a load having appreciable inertia.

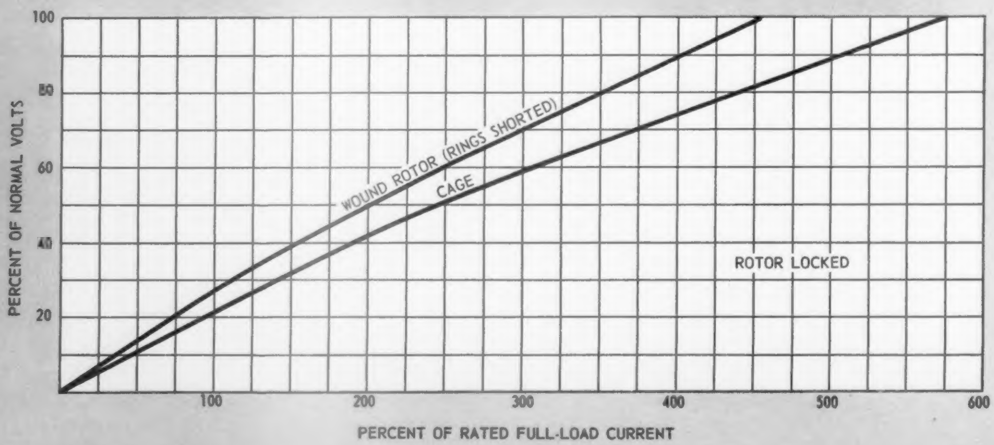
With these large currents flowing through the short-circuited rotor, rotor coils may become hot enough to damage coil insulation and band wire packing.

Excessive heating may loosen the steel band wire which secures coil ends against centrifugal force. Also, prolonged high rotor currents can soften or melt the solder used frequently for rotor conductor end connections. Motor operation under these conditions will eventually damage both rotor and stator.

This condition may not be immediately apparent, but may develop in repeated starts of even low inertia loads. For example, a 700-hp, 1200-rpm wound-rotor motor started with slip rings short-circuited failed because of band wire slippage. The motor drove a centrifugal pump and had operated for several months with slip rings shorted during starting periods.

In general, troubles arise because the rotor windings, insulation, banding, and connections are designed to carry relatively low currents, not the large currents associated with shorted slip-ring starting.

LOCKED-ROTOR current is higher for cage than for wound-rotor type with rings shorted and with identical stator in low speed motors. **(FIGURE 6)**



The distorting effects of large starting currents on the stator coil ends cannot be ignored. Appreciable movement of the coil ends can harm the insulation, especially if it is old. Cracking of the surface film can permit entrance and penetration of harmful conducting materials.

Reduced-voltage starting of a wound-rotor motor with shorted slip rings will not alleviate the situation because of the poor torque characteristics during acceleration. Furthermore, reduced-voltage starting facilities are not usually available or contemplated when starting with slip rings shorted is being considered.

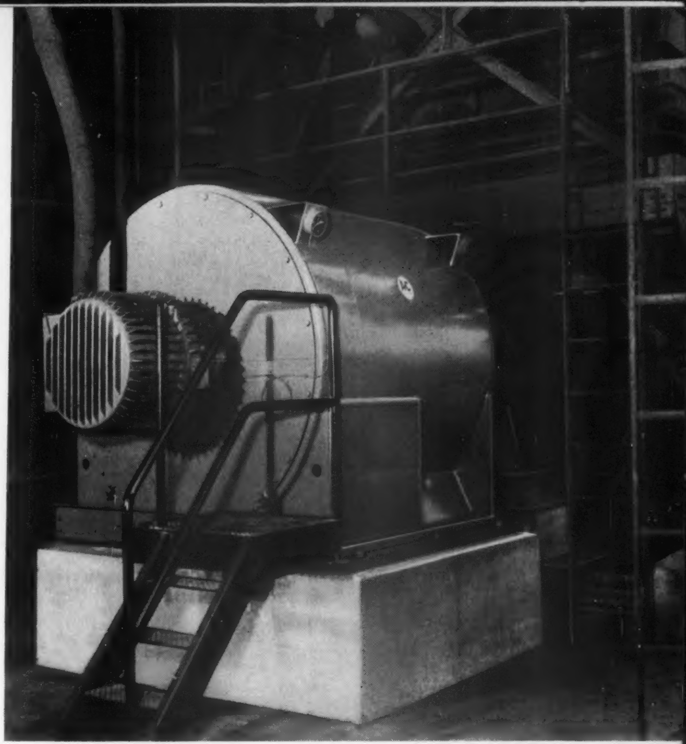
Starting torque is low with shorted slip rings

As mentioned previously, once the wound-rotor motor attains full speed, it will carry its full load satisfactorily with the rings shorted. Of particular interest, then, is the torque at standstill and during the accelerating period.

The amount of torque developed at breakaway is dependent upon the relationship between stator and rotor poles. In the wound-rotor motor, the insulated rotor winding is similar in all essential respects to the stator winding. As in the stator, the number of slots in the rotor, per pole or pair of poles, is preferably divisible by the number 3 for three-phase machines. (This is not a requirement and frequently is not the case in the cage-type induction machine.) Since the stator and rotor slots per pole or pair of poles of a wound-rotor motor are divisible by 3, there will be many positions in which the stator and rotor teeth are in locked positions while large currents are flowing because the slip rings are shorted.

This locking effect[1] can be severe enough to prevent the rotor moving away from standstill. In some motors, the locking effect is insufficient to overcome the rotor winding torque because of rotor copper losses. The motor will start if the connected load breakaway or static torque is not large. After the motor with rings shorted has moved from standstill position, the load can be accelerated to full speed.

[1]*Electrical Machine Design*, by Alexander Gray, McGraw-Hill Book Co., Inc.; New York, N. Y.

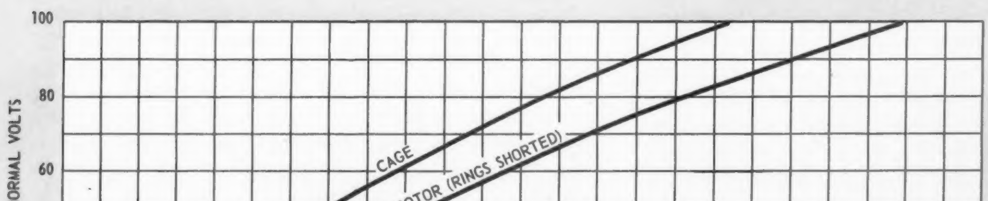


HEAVY MACHINERY like the dredge pump driven by this 1000-hp motor requires wound-rotor type for breakaway torque. **(FIGURE 8)**

However, if the load inertia is high, the motor and its connected load will accelerate slowly. The slower the acceleration, the more intense will be the heating in the stator and rotor. The harmful effects have already been pointed out.

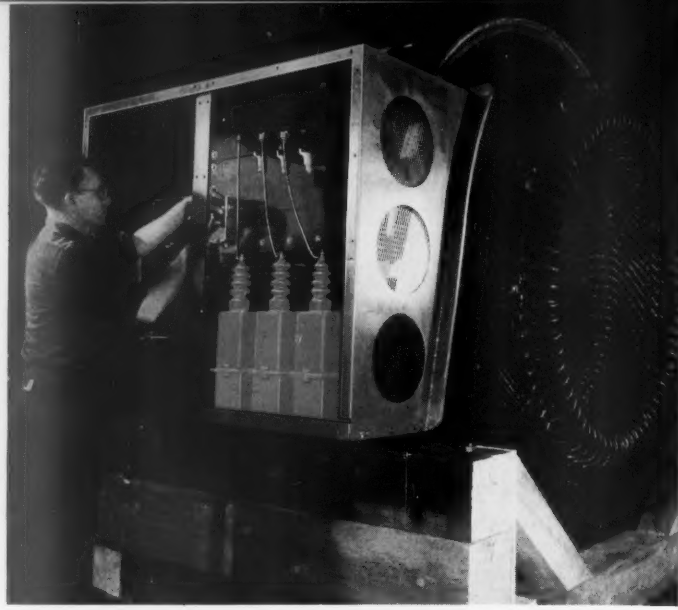
Starting with shorted rings not recommended

Starting a phase-wound-rotor induction motor as a cage motor by shorting the slip rings is likely to be unsatisfactory. While some motors may start with external load, the torque developed is very small. Because of the poor breakaway torque chracteristics, the starting of any connected load or even an unloaded motor is never certain. Even if the connected load were moved from its static position, the load inertia to be accelerated would have to be very low. In general, therefore, short-circuiting the slip rings of a wound-rotor motor, thus starting it like a squirrel-cage induction motor, is not recommended.



LOCKED-ROTOR current in high speed machines is less in cage motor than in a wound-rotor type with shorted rings and identical stator. **(FIGURE 7)**

SHORT CUTS in Surge Analysis



SURGE CAPACITORS will protect 8000-hp, 1200-rpm, synchronous compressor drive motor shown being readied for shipment. Capacitance can be determined by simplified approach to problem.

by **A. H. KNABLE**
Switchgear Department
Allis-Chalmers Mfg. Co.

Traveling wave theory can help you solve problems involving real circuit components in a power distribution system.

A NEW APPROACH in presenting traveling wave reflections has speeded up solutions to a variety of problems involving surge voltages. Problems vary from the proper type and location of lightning arresters in a power distribution system to the choice and proper placement of surge capacitors for motor circuit protection.

Before considering the solutions to problems, the knowledge of how to handle reflections must be added to the basic concepts of surge analysis. In the basic theory it is noted that reflections from remote parameters seldom enter in the problem; however, reflections from the immediate circuit parameters do. To analyze these local reflections, a reflection lattice is constructed as a systematic method of keeping track of the reflections that occur.

The initial wave voltage calculated will, upon encountering a junction point, partially reflect and partially continue in the same direction of travel as the initial wave. An example of a junction point might be a line connected to a bus having several feeder cables. Another example is a line connected to a transformer. In this case there is nearly 100 percent reflection, with very little of the initial surge passing through. Furthermore, if a line is connected to a circuit breaker that is open, the initial voltage wave will be totally reflected. First, it is necessary to determine the exact relation between the reflected portion of the initial surge and the transmitted portion of the initial surge. This relation can be expressed by the following equation:[1]

$$e'_1 = \left(\frac{Z_0(p) - z_1}{Z_0(p) + z_1}\right) e_1 \qquad (1)$$

This equation shows that the reflection operator (a multiplying factor to the initial voltage, e_1) is the circuit impedance, $Z_0(p)$, which the wave sees through the junction point at time zero minus the surge impedance, z_1, over which it is traveling, divided by the same circuit impedance plus the surge impedance on which it is traveling. Thus the reflected voltage is equal to the initial voltage multiplied by the reflection operator. The transmitted portion of the wave, e_0, is equal to the initial voltage multiplied by the refraction operator. The transmitted voltage may be expressed as:[1]

$$e_0 = \left(\frac{2Z_0(p)}{Z_0(p) + z_1}\right) e_1 \qquad (2)$$

This can be rearranged to:

$$e_0 = \left(1 + \frac{Z_0(p) - z_1}{Z_0(p) + z_1}\right) e_1$$

$$= (1 + a) e_1 = b e_1$$

$$\therefore\ b = (1 + a) \qquad (3)$$

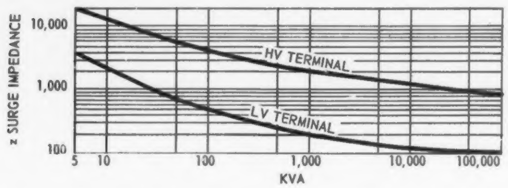
Where a is used to represent the reflection operator, b is used to represent the refraction operator, and e_0 is the transmitted wave expressed in terms of the refraction operator and initial voltage. Thus we obtain a relationship between the reflected and the transmitted portions of the wave. Since we know the relations for magnitude, the only additional factor involved in a lattice diagram is time.

TABLE I

Parameter	Feet/μs
1. Overhead line	1000
2. Cable	500
3. Rotating machine	50

μs = microseconds

The length of a line upon which the reflections are being analyzed is not expressed in feet but rather in seconds. The simple relation between feet and seconds is shown in Table I. The figures shown are generally accepted values. Thus 100 feet of overhead line is equivalent to $0.1\mu s$ and 100 feet of cable is equivalent to $0.2\mu s$.



TRANSFORMER surge impedance varies with rating of the unit. Approximate values can be obtained from curve. **(FIG. 1)**

A helpful list of reflection operators for various circuit equipment is given below:

1. *Transformer* $a =$ Reflection operator
   a. Cable to small transformer $a = \left(\frac{10{,}000 - 50}{10{,}050}\right) = 0.99$
   b. Cable to large transformer $a = \left(\frac{3000 - 50}{3050}\right) = 0.97$

The approximate relation between surge impedance and transformer size can be obtained from Figure 1.

2. *Rotating Machine*
   a. Cable to small machine $a = \left(\frac{1000 - 50}{1050}\right) = 0.90$
   b. Cable to large machine $a = \left(\frac{100 - 50}{150}\right) = 0.33$

The rotating machine surge impedance varies with time and machine size. However, the value of 1000 ohms for smaller machines and 100 ohms for larger machines might be used for approximation purposes.

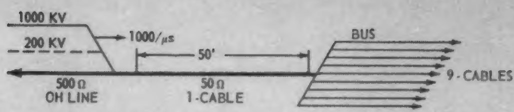
3. *Open End Line* $a = (+)\ 1$
4. *Grounded End Line* $a = (-)\ 1$
5. *Lightning Arrester*
   a. Before flashover $a = (+)\ 1$
   b. After flashover $a = (-)\ 1$

A lattice can best be explained by means of a few examples. It should be noted that the lattice is only a sketch and is convenient for recording the calculations. It is not, however, to be interpreted as a graph constructed to some predetermined scale.

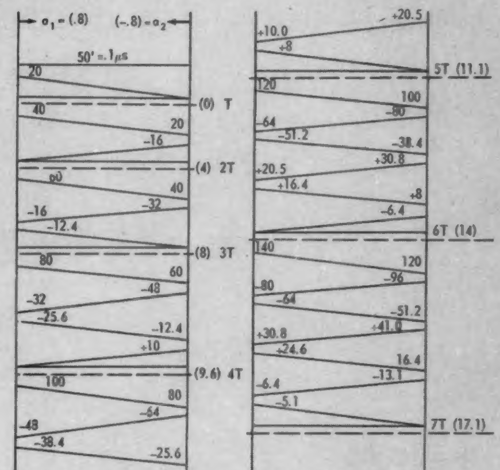
Example 1

A reflection lattice may be used to prove that a short piece of line between two points of a circuit can be omitted (by assuming two points are brought together as one) without appreciable error in the results.

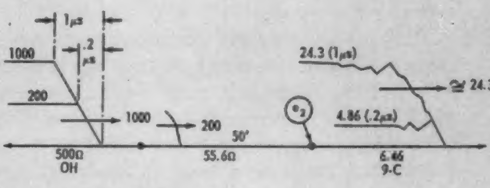
The circuit configuration in Figure 2 is as shown with the reflections sketched in Figure 3. Figures 4, 5, and 6 show the exact circuit, an equivalent circuit and a plot of the lattice voltages, respectively.



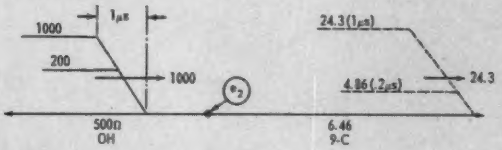
CIRCUIT configuration is established. **(FIGURE 2)**



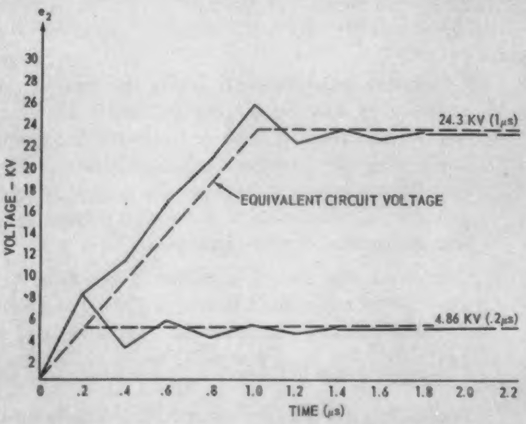
REFLECTION LATTICE shows that little error is obtained by eliminating the short line calculations. **(FIGURE 3)**



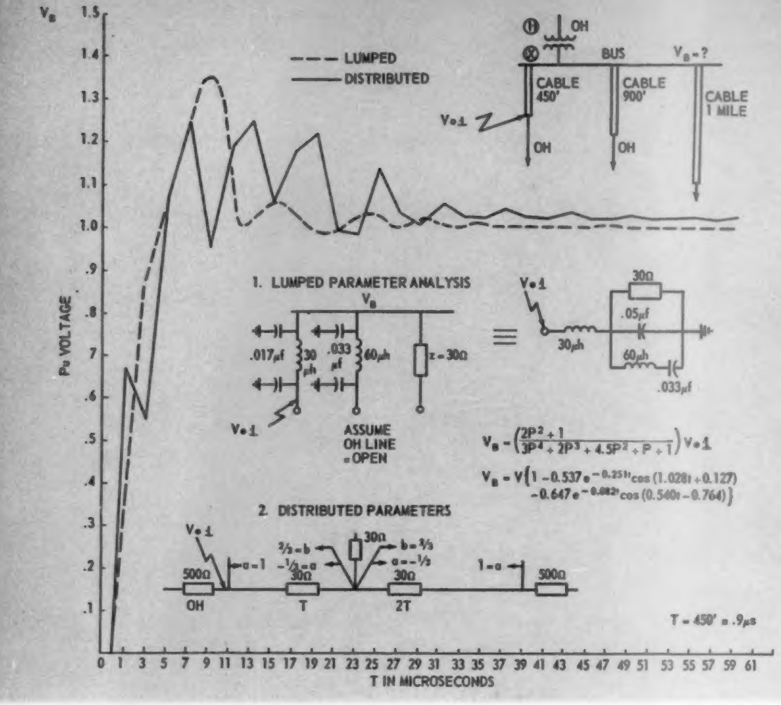
EXACT CIRCUIT includes the short line. **(FIGURE 4)**



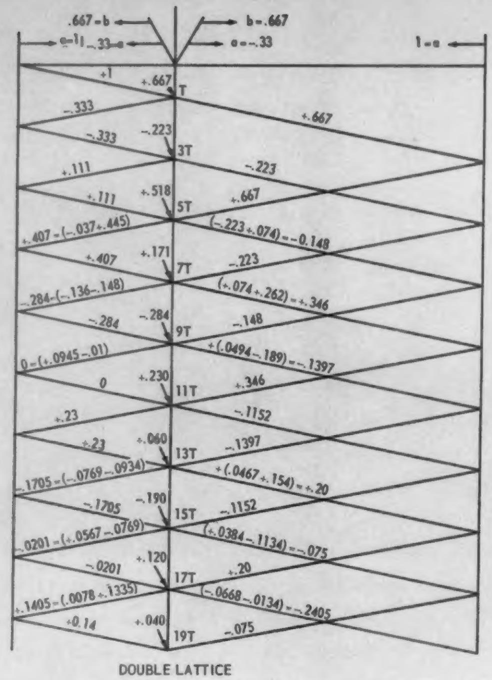
EQUIVALENT CIRCUIT omits the short line. **(FIGURE 5)**



PLOT of lattice diagram voltages shows the difference in results expected when using circuit of Figure 5. **(FIG. 6)**



LUMPED PARAMETER method is compared with the distributed parameter method for the distribution circuit shown. **(FIGURE 7)**



DOUBLE LATTICE of the distributed parameter method saves considerable time. However, results are comparable. **(FIG. 8)**

Example 1 shows that the short cable causes a slight distortion in the outgoing voltage e_2, but for practical purposes the equivalent circuit voltage would yield the same results. However, the validity of assuming the short line as nonexistent not only depends on how short is short, but also on the magnitude of the incoming surge. If the surge is high in magnitude (1000-kv peak) the slight distortion is negligible. On the other hand, if the incoming surge is 200-kv peak, the distortion on the outgoing wave may or may not be negligible, depending on the purpose of the analysis. Furthermore, if a unit step function surge (straight front) were used instead of the sloping front surge shown, this analysis would be uninformative.

Example 2

The following example illustrates, first, the method of constructing a double lattice and, second, that there are problems in which a lattice diagram analysis can be made in much less time than an analysis by operational methods and lumped parameter representation.

In constructing a double lattice, the ratio of one length to the other must be adhered to, but the absolute scale of the double lattice is arbitrary, as with the single lattice. In the lumped parameter analysis of Figure 7, the assumption that the overhead lines are the same as an open circuit is necessary. However, if distributed parameters are used, this assumption need not be made.

In the lattice shown in Figure 8, the value of 1.0 was used as the reflection operator at the cable overhead line junction points to compare the results of both solutions. The exact value of $\left(\dfrac{500-30}{500+30}\right) = 0.88$ could have been used just as easily as the assumed 1.0. The lumped parameter analysis is shown in operational form as a fourth degree equation in p, which after considerable effort can be expressed as shown in terms of t, which after more effort can be plotted as shown by the broken line.

Examples 1 and 2 raise another question. In Example 1 a sloping front surge was used, and in Example 2 a straight front surge was used. Since it is simpler to use a straight front surge than a sloping front surge, it is useful to know when a sloping front must be used and when a straight front can be used, shown in Example 3.

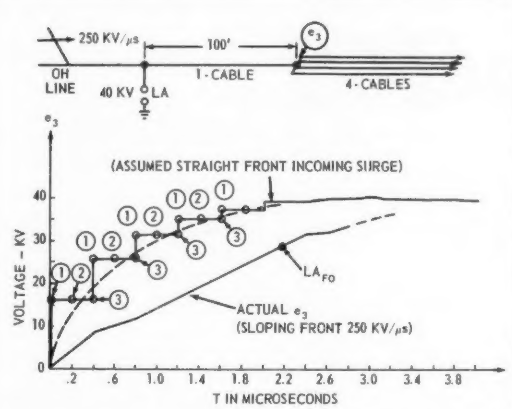
Example 3

This example involves two parts, one with an arrester and the other without. First, we will consider the case with an arrester.

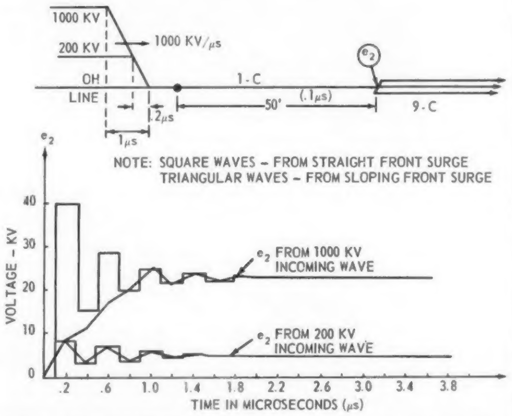
The factor that governs whether or not a straight front wave can be used is the relation between arrester sparkover voltage and line length involved in the analysis. If the arrester sparks over before the first reflection returns to the arrester, the sloping front surge can be replaced by a straight front surge with no change in the long-time slope of the resultant surge. Since this condition exists frequently, a straight front surge can be used in the majority of cases to be analyzed. Figure 9 shows such an analysis.

We can see that if the incoming wave has a 250-kv per microsecond front, the assumption that it has a straight front is not valid. On the other hand, if the incoming wave has a 1000-kv per microsecond front, the assumption that it has a straight front would be valid because point 1 would be shifted to point 2; and if 500 kv per microsecond is the front, then point 1 is moved to point 3, which represents the limit of validity. Beyond that the wave takes a completely different form, as shown for a 250-kv per microsecond front.

In the second case, where no arrester is involved, the governing factor is the relation between the natural peak voltage and the line length involved in the analysis. If



STRAIGHT FRONT incoming surge can be assumed in most but not in all cases where an arrester is involved. **(FIGURE 9)**



WITH NO ARRESTER, relation between natural peak voltage and line length determines if straight front can be used. **(FIG. 10)**

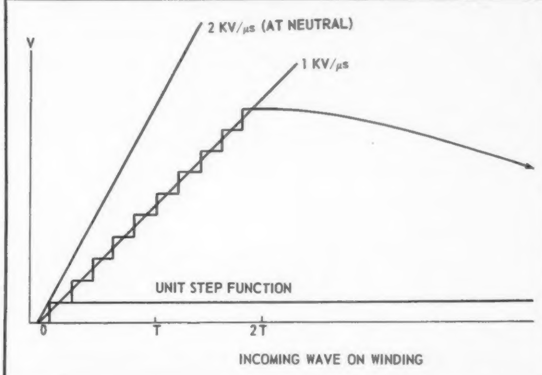
the time to natural peak of the wave is equal to or less than twice the line length upon which the reflections will occur, the straight front wave can be used in place of the sloping wave. The straight front wave does not lend itself as frequently here as it does in the first case. Figure 10 shows an analysis of the second case.

The 200-kv incoming wave has a 0.2 microsecond ($0.2\mu s$) to peak time, which is within the 2 x 0.1 microsecond length of cable time. The straight front wave, therefore, can yield useful results; that is, the peaks of the square wave have the same value as when the sloping front wave is used, and all that has to be changed is the slope of the square wave.

On the other hand, the 1000-kv peak wave has to be represented as a sloping front wave, since $1\mu s > (2 \times 0.1\mu s)$; if a straight front wave were used, the results would be incorrect, as is shown in the sketch of Figure 10.

Example 4

Internal oscillations in motor windings introduce a problem slightly different than those covered so far. A study of these oscillations is sometimes required to determine the voltage distribution on the winding. By simple reflection analysis, with the aid of superposition, this problem can be solved in a minimum amount of time and effort. The analysis begins with Figure 11, which shows



STEEP FRONT WAVE is changed to shallow front wave by action of surge capacitor at machine terminals. **(FIG. 11)**

the resultant incoming wave as having a slope of 1 kv per microsecond. The unit step function voltage is used to determine the standing wave voltage distribution characteristic, as shown in Figure 12. Then by superposition the resultant voltage for representing the incoming wave can be obtained, as shown in Figure 13, which is for the 20 percent point on the winding. Similar analysis can be carried out for the other points on the winding from which the voltage distribution shown in Figure 14 can be constructed. This is the actual voltage distribution for a machine whose winding has an ungrounded neutral and is connected to a long cable.

Example 5

The value of capacitance needed to keep the voltage stress on turn-to-turn insulation of a motor to a permissible value can be determined by using wave analysis.

Consider the case of a motor connected to a source by means of a cable and having a capacitor-arrester combination mounted at its terminals. This circuit might be sketched as shown in Figure 15.

To obtain e_3 in Figure 15, a simple voltage impedance ratio can be employed. The ratio may be reduced to yield the following solution:

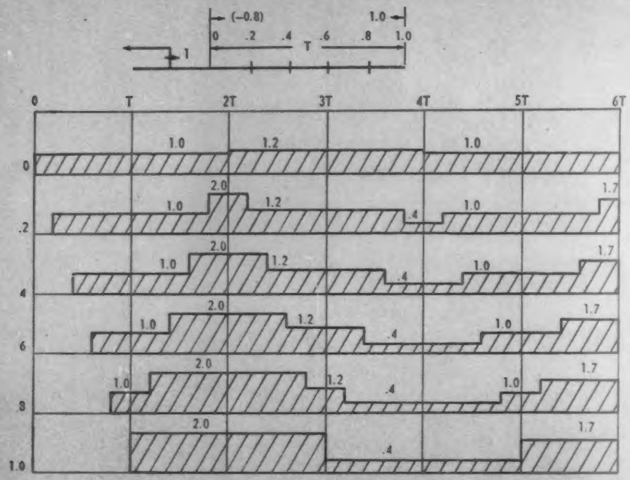
$$e_3 = \left(\frac{\dfrac{z}{pc\left(z + \dfrac{1}{pc}\right)}}{z_c + \dfrac{z}{pc\left(z + \dfrac{1}{pc}\right)}} \right) 2e_2$$

$$e_3 = \left(\frac{z}{pczz_c + z_c + z} \right) 2e_2$$

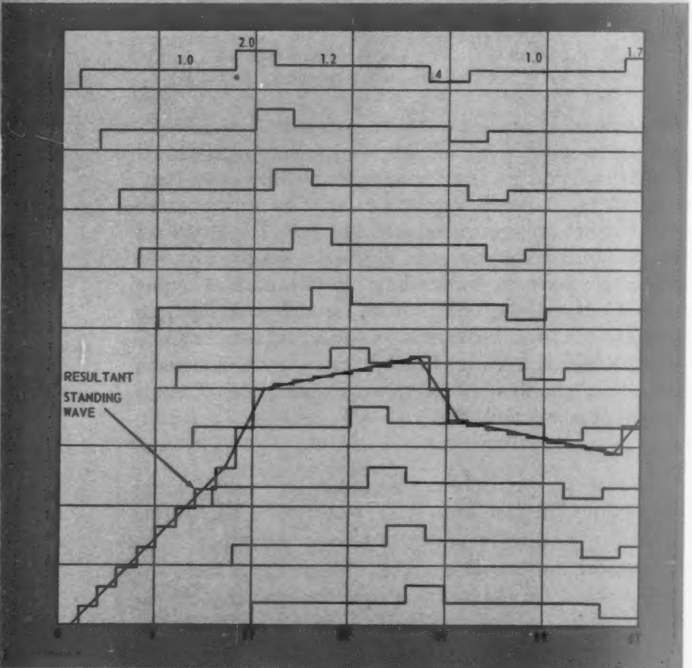
$$e_3 = \frac{2e_2}{cz_c} \left(\frac{1}{p + \dfrac{zc + z}{czz_c}} \right) \text{ ; Let } \alpha = \left(\frac{zc + z}{czz_c} \right)$$

$$e_3 = \frac{2V_{LA}}{cz_c} \left(\frac{1}{p + \alpha} \right) \cdot f$$

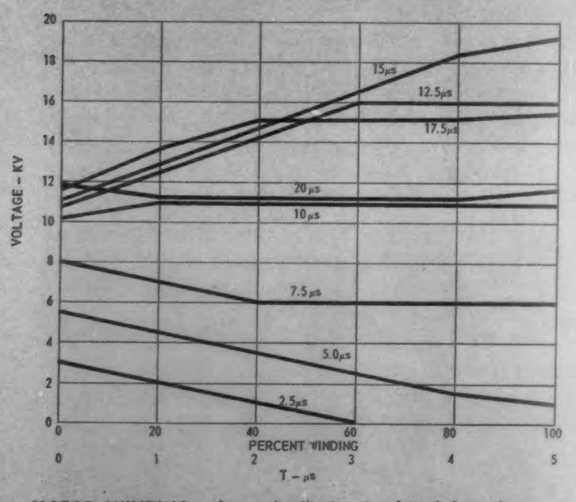
where $\cdot f$ is the unit step function.



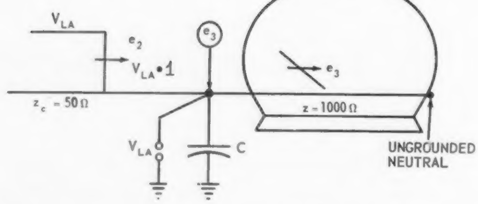
UNIT STEP FUNCTION of Figure 11 is used to determine standing wave voltage distribution in the winding. **(FIG. 12)**



SUPERPOSITION at proper time intervals of the unit step function produces the standing wave function shown. **(FIG. 13)**



MOTOR WINDING voltage distribution is plotted for other points using analysis such as that of Figure 13. **(FIGURE 14)**



SURGE CAPACITOR rating needed to protect the motor windings can be obtained by using wave analysis. **(FIG. 15)**

$$e_3 = 2V_{LA}\frac{z}{z_c + z}(1 - e^{-\alpha t})$$

$$\frac{de_3}{dt} = m_3 = \frac{2V_{LA}}{cz_c}e^{-\alpha t}$$

$$m_{3\ \text{max.}} = \frac{2V_{LA}}{cz_c}$$

Where $z = 1000$, $z_c = 50$, $c = .25$, and $V_{LA} = 10$ kv:

$$m_3 = \frac{2 \times 10\ \text{kv}}{.25 \times 50} = 1.60\ \text{kv}/\mu\text{s}$$

Results of an analysis such as this are shown in Table II:[3]

TABLE II

Turn Length (Ft)	Machine Kv	Capacitance in μfd for the Following Permissible Turn Voltages			
		0.5 Kv	1.0 Kv	2.0 Kv	4.0 Kv
5	2.3	.16	.07	.04	.02
	4.0	.24	.12	.06	.03
	6.6	.38	.20	.10	.05
	13.2	.75	.36	.18	.10
10	2.3	.30	.16	.07	.04
	4.0	.50	.24	.12	.06
	6.6	.80	.38	.20	.10
	13.2	1.50	.75	.36	.18

It should be noted that an intimate knowledge of rotating machine insulation is not necessary to make a useful analysis. By tabulating results between practical limits as in Table II, the analysis becomes useful to others having this knowledge.

The problem of internal oscillations on machine windings in Example 4 can be used in this problem to answer the question of whether or not internal oscillations create a more severe gradient between turns than the initial incoming surge.

We can conclude that the internal oscillations create a gradient which approaches twice that created by the initial incoming surge. However, when the initial incoming surge doubles at the neutral, the gradients created are equal.

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2. "Surge Characteristics of Two Winding Transformers," Reinhold Rudenberg, AIEE *Transactions,* Vol. 60, 1941, pp 41-85.
3. "Locating Surge Arresters and Capacitors for Rotating Machine Protection on Industrial Power Systems," A. H. Knable and D. Dalasta, AIEE Paper CP-57-304.

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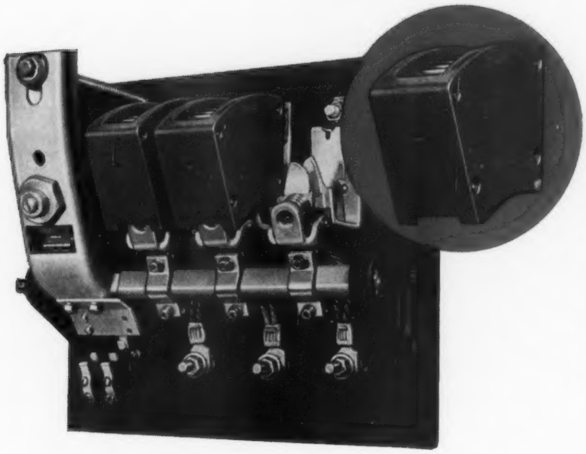

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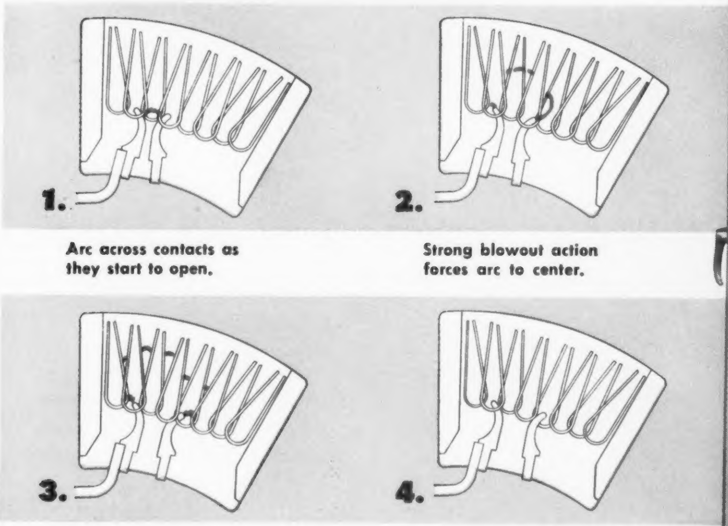
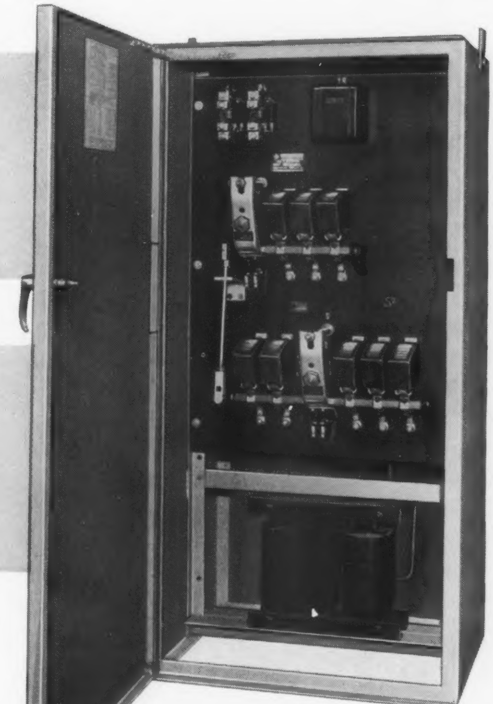


1. Arc across contacts as they start to open.

2. Strong blowout action forces arc to center.

3. Arc rupturing.

4. Contacts fully open—arc extinguished.



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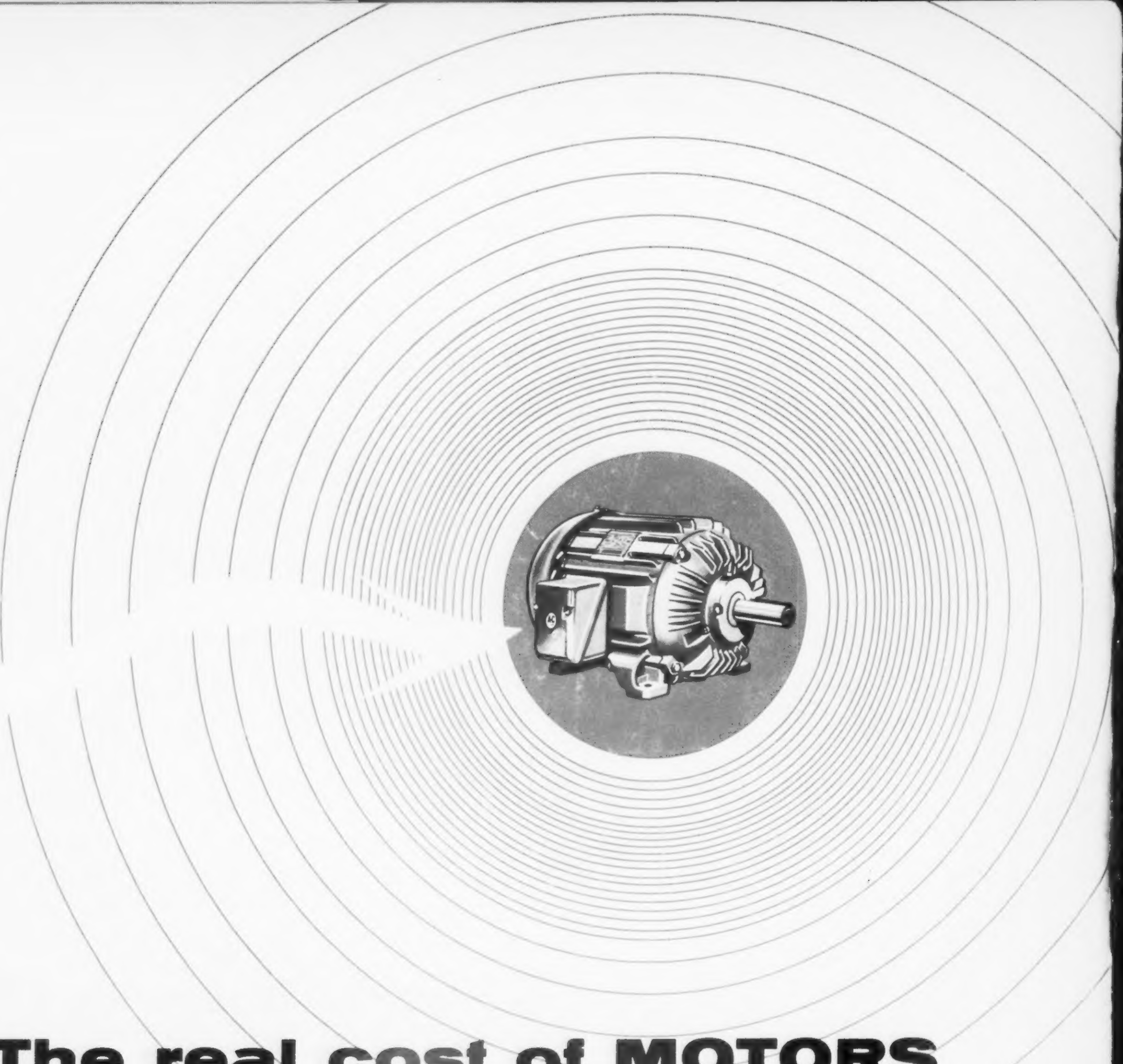

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